LABORATORY PHYSICS

MILLIKAN - GALE - BISHOP

A FIRST COURSE IN LABORATORY PHYSICS

FOR SECONDARY SCHOOLS

BY

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PREFACE

This course of about fifty laboratory exercises represents an endeavor to bring beginning students of physics into direct first-hand contact with the most significant of the principles of the subject and with their applications to daily life.

Since the precise method of accomplishing this end will depend upon the sort of laboratory equipment which is available, the course has been given considerable flexibility by introducing alternative experiments.

Thus, if gas is not accessible the student will omit Exp. 5, but will get exactly the same principle through performing Exp. 5 A. Or, if the laboratory is not equipped with commercial ammeters and voltmeters, Exp. 31 will be omitted and Exp. 31 A performed. Similar choices will be found indicated throughout the text.

Another feature of the course is that the experiments do not presuppose any previous study of the subject involved, or any antecedent knowledge of physics. The laboratory work may be kept in advance of the classroom discussion throughout the entire course if desired. Indeed, in their own elementary work the authors prefer to let more than half of the experiments constitute the student's first introduction to the subject treated. Furthermore, students are neither instructed nor advised to study their experiments before entering the laboratory, for each experiment has been arranged to carry with it its own introduction.

Problems on the practical transformations of energy have been given the important place in this course which they merit, and it is hoped that an advance has been made in the way in which they are treated. Thus, in comparing the efficiencies of two different appliances which accomplish the same result, as, for example, an electric stove and a gas stove, the fact has often been overlooked that in daily life people are interested in efficiency only as it affects *cost* of operation. The emphasis has here been thrown, therefore, on the real test of efficiency from the consumer's standpoint, namely the relative *cost* of a given output rather than on the mere ratio of energy output to energy input.

In order to instil in the pupil the habit of orderliness and to teach him to collect and organize related data in such a way as to draw conclusions from it, a form of record has been placed at the end of most of the experiments. This procedure also enables the teacher to check up the experiments with a minimum expenditure of time and energy. In the case of qualitative work the Record of Experiment has, as a rule, been omitted.

For the benefit of those who use both this book and the classroom text entitled "A First Course in Physics," a suggested time schedule for a thirty-six weeks' school year is inserted in Appendix A. Whether this particular schedule is followed or not, it seems to the authors a matter of great importance that each teacher begin his year with some well-considered time schedule before him, and that he plan each lesson and make his omissions and additions with this schedule in mind. Otherwise it almost invariably happens that the subjects treated in the first half of the text receive a disproportionate amount of time.

The initial cost of equipment for satisfactorily conducting this course with classes of say twelve pupils need not exceed two or three hundred dollars. If commercial electrical instruments are employed, however, the cost may of course reach a much higher figure.

R. A. M.
H. G. G.
E. S. B.

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LABORATORY PHYSICS

EXPERIMENT 1

TO DETERMINE Π, THE RATIO OF THE CIRCUMFERENCE OF A CIRCLE TO ITS DIAMETER

I. Measurements. (*a*) *Measurement of circumference.* Scratch a fine line *A* along a radius of an accurately turned disk.

Place *A* accurately above some division *B* on the meter stick (Fig. 1), and roll the disk between the thumb and finger until *A* is again in contact with the meter stick. Record the positions of *A* in centimeters, by noting first the whole number of centimeters, then the number of millimeters in the tenths place, and lastly the estimated tenths of a millimeter in the hundredths place.* The circumference is the difference between this reading and the starting point.

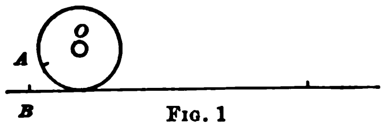


FIG. 1

Starting at different marks on the scale, repeat four times and take the average of the five trials as the circumference.

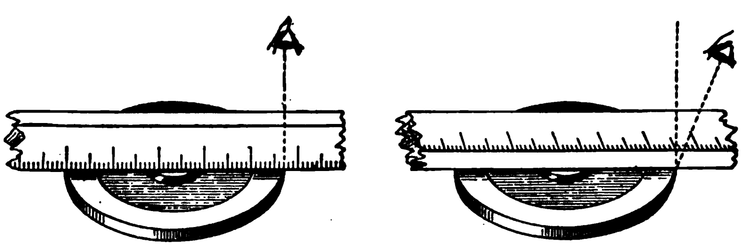
(*b*) *Measurement of diameter.* Lay the disk flat on the table. Place the meter stick on edge (Fig. 2) so that the centimeter face is along a diameter and so that some centimeter division coincides with one edge of the disk. Record the diameter, estimating tenths of a millimeter.

Repeat four times, measuring different diameters, and take the average of the five trials as the diameter.

II. Computation. (*a*) The last figure of each measurement was estimated and therefore uncertain.

(*b*) Retain one more uncertain figure in the average than in the individual measurements.

(*c*) After every multiplication or division retain the same number of significant figures in the product or quotient that there are in that factor which has the smallest number of significant figures. The numbers 583, .409, 1.03, .00110 have three significant figures each. Thus, ciphers before a number in a decimal fraction less than one are not significant figures.



Correct method of using meter stick FIG. 2 Incorrect method of using meter stick

(*d*) Keeping in mind what has been said about significant figures, compute π from your mean values of the circumference and the diameter.

* Unfamiliarity with the metric system may make it seem more natural to estimate in halves, thirds, or quarters, but it will be easy to express the result in tenths if one reflects that .4 is a little less and .6 a little more than .5, or 1/2; .2 a little less and .3 a little more than .25, or 1/4; .1 a little less than .2, or 1/5, etc.

III. Per cent of error. The per cent of error in any product or quotient can best be illustrated by an example. If in the measurements $\frac{200 \times 1000}{100} = 2000$ an error of $+1\%$ were made in the 200, $+.5\%$ in the 1000, and $-.5\%$ in the 100, the result would be $\frac{202 \times 1005}{99.5} = 2040+$. Thus we see that the result 2040 is 40, or 2%, larger than the true value 2000. We also see that in this case the errors 1%, .5%, and .5% added together produce a total error of 2%. Thus, to find the error of any experimental result which is obtained by taking the product or quotient of several physical measurements, add the per cents of error in each of the factors entering into such product or quotient, and the sum of these will be the per cent of error allowable in the final result. To find the per cent of error in any one of the factors, find what per cent the probable error in measuring that quantity is of the quantity itself.

Answer in your notebook the questions which appear at the end of the experiment.

Questions. *a.* What per cent of error would have been introduced into the diameter by an error of .01 cm.?

b. What per cent of error would have been introduced into the circumference by an error of .02 cm.?

c. Your value of π might reasonably be in error by the sum of these two errors. State, therefore, whether your result is as accurate as reasonably careful measurements would give.

RECORD OF EXPERIMENT

TRIAL	DIAMETER IN CM.	CIRCUMFERENCE IN CM.
1		
2		
3		
4		
5		
Mean =		Mean =

$\pi = \frac{\text{circumference}}{\text{diameter}}$ = ...

Correct value = 3.1416

Difference, or error = ...

Per cent of error $= \frac{\text{error}}{\text{a 1\% error}} = \frac{\text{error}}{.0314}$

= ....

EXPERIMENT 2

HOW TO FIND THE VOLUME OF A CYLINDER

I. By computation from linear measurements. (*a*) *Measurements.* With a meter stick measure to tenths of a millimeter three different depths of the cylindrical vessel shown in Fig. 8.

Measure the *inside* diameter D as in Exp. 1 (see Fig. 2).

Take the above measurements with a vernier caliper,* if available.

(*b*) *Computation.* Volume of cylinder = area of base × depth, or volume $= \frac{\pi D^2}{4} \cdot L = \pi R^2 L$ where R is the radius and L is the depth. Before computing read carefully Exp. 1, II.

In this experiment make all computations a part of the final record.

Questions. *a.* If the *measured* diameter of a circle is 10.1 cm., and the *true* diameter is 10 cm., what will be the per cent of error in the area of the circle?

b. What per cent of error will be introduced into the computed value of the area of a circle, if there is an error of 0.3 per cent in the measurement of the diameter?

c. Allowing .01 cm. error in the mean values of D and L, find the per cent of error in the volume.

II. By weight of water contained by cylinder. (*a*) *Weighing cylinder by method of substitution.* Place the empty cylinder with its ground-glass cover on the pan B (Fig. 3) of the balance and add to pan A any convenient objects, such as pieces of iron, shot, and bits of paper, until the pointer stands opposite the middle mark at s, the rider R being at zero.

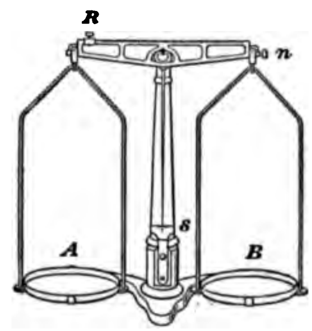


FIG. 3

Then replace the cylinder and its cover by weights from the set in the following way. Find by trial the largest weight which is not too large, and place it on pan B. Add the equal weight, or, if there is no equal, the next smaller one, if it is not too heavy; add again the equal or next smaller weight, and so on, always working down from weights which are too large. This saves the delay and annoyance caused by adding a large number of small weights and at last finding that their sum is still too small.

When a balance has been obtained to within 10 g., slide the rider R along the graduated beam until the pointer stands opposite the middle mark at s. The weight of the body is then the sum of the weights on the pan plus the reading of the left edge of the index R on the graduated beam. Since each division of the scale on the beam represents one tenth of a gram, by estimating to tenths of a division we can obtain the weight by this method to hundredths of a gram.

* The vernier is a device for measuring fractional parts of a scale division. It consists of a movable scale AB arranged to slide along a fixed scale CD (Fig. 4). The object to be measured is placed between the jaws EF, which are so made that when they are in contact the zero of the sliding scale is opposite the zero of the fixed scale. Ten divisions of the sliding scale AB are made equal to nine divisions, that is, 9 mm., on the main scale CD; hence one vernier division is equal to .9 mm. Fig. 5 (1) shows the vernier scale and the fixed scale enlarged. Here the zero of the vernier is exactly opposite the 5-mm. mark of the fixed scale, this being the relative position of the two scales when an object 5 mm. in diameter is placed between the jaws. Since one division on AB is equal to only .9 mm., while one division on CD is equal to a whole millimeter, it follows that the mark 1 of the sliding scale AB is .1 mm. behind the mark 6 of the fixed scale; 2 on AB is .2 mm. behind 7 on CD; 3 is .3 mm. behind 12, etc. Therefore, if the sliding scale were moved up so as to bring its mark 1 opposite the m

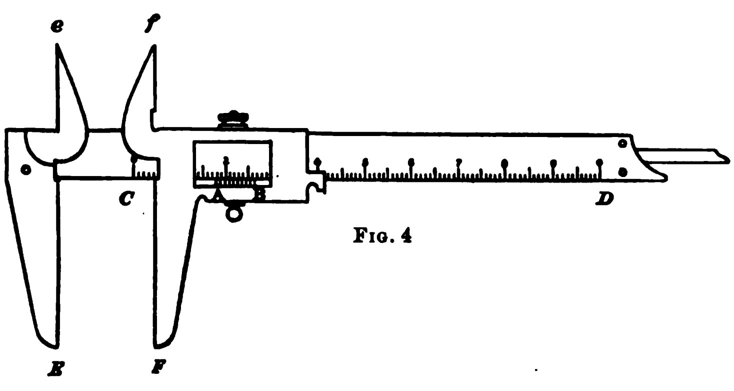


FIG. 4

EXPERIMENT 4

HOW PRESSURE BENEATH THE FREE SURFACE OF A LIQUID VARIES WITH DEPTH

I. Verification of the law of depths and densities. (*a*) *Measurements in water.* Immerse the manometer M of Fig. 9 to the greatest depth possible in the long glass vessel V filled with water.* A length of at least 1 m. is desirable (see tube of Exp. 40).

Record the surface reading where the level of the liquid touches the meter stick. (Read where the level strikes the meter stick and not the point up to which the water laps upon the meter stick.) Then record the level of the mercury both in the open arm of the manometer and in the arm against which the liquid pressure acts. (In the last two readings be careful to hold the eye so that the line of sight is at right angles to the meter stick, then take the reading at the top of the curved mercury meniscus, estimating the reading to tenths of a millimeter.) Evidently the depth is the difference between the first and third readings, and the pressure in centimeters of mercury is the difference between the second and third readings.

Raise the manometer about 10 cm. and make similar measurements. Continue in this way, raising the manometer about 10 cm. at a time, until a depth of 10 or 15 cm. is reached.

(*b*) *Measurements in gasoline.* Fill the vessel V with gasoline instead of with water and make a similar set of observations for gasoline.

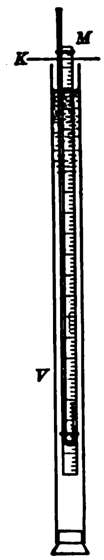


FIG. 9

II. Algebraic or analytic representation of a direct proportion. From your data it will be seen that within the experimental error the result obtained, for any liquid, by dividing the depth H by the pressure P is always the same, or, stated algebraically,

$$\frac{H_1}{P_1} = \frac{H_2}{P_2} = \frac{H_3}{P_3}, \text{ etc., or } \frac{H}{P} = \text{constant.}$$

Hence in the equation $\frac{H}{P} = \text{constant}$, if H is made 2, 3, 4, etc. times as great, P will also be 2, 3, 4, etc. times as large, since their ratio $\frac{H}{P}$ remains unchanged.

Whenever two quantities, such as H and P above, vary in such a way that doubling one doubles the other, trebling one trebles the other, etc., the one is said to be *directly proportional* to the other, or to *vary directly* with the other.

The first equation for a direct proportion may also be stated by $\frac{P_1}{P_2} = \frac{H_1}{H_2}$, $\frac{P_1}{P_3} = \frac{H_1}{H_3}$, etc., or again by $P \propto H$, where $\propto$ is read "is proportional to."

III. Graphical representation of a direct proportion. That the pressure in any liquid is directly proportional to the depth is shown graphically by Fig. 10. The curve, or "graph," for a direct proportion is seen to be a straight line.

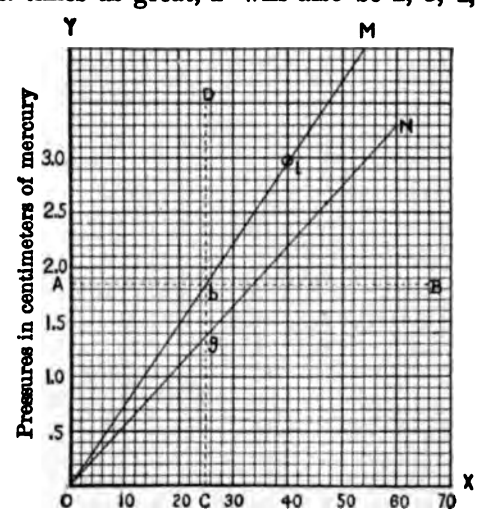


FIG. 10

On a sheet of coördinate paper plot your own data. Choose a scale along OX, that is, to the right of the origin O, so that the greatest depth will come near the right side of the page. (For example, the greatest depth plotted in Fig. 10 was 60 cm. in gasoline.) Choose a different scale along OY, that is, above the origin, so that the greatest pressure will come at least halfway to

* A piece of glass tubing about 1 m. long and 4 or 5 cm. in diameter, closed at the bottom with a rubber stopper, answers the purpose admirably.

Use ¼-in. tubing for manometer. Support at 10 cm. intervals with knitting needle K.

the top of the sheet of paper. In general, choose the scale in each case so that the greatest distance along OX (abscissa) and the greatest distance along OY (ordinate) are roughly of the same magnitude. Then a single point will represent a set of readings for a given depth, the distance the point is to the right of O representing the depth, and the distance it is above O representing the pressure. Having plotted all of these points for the set of data on water, with a sharp pencil and straightedge draw a line through O which passes as close as possible to all of the plotted points, leaving half the points on either side of the line in case the line does not pass through all of them. This is a graphical way of averaging.

Questions. *a.* Why must the straight line be drawn through O, the origin?

b. Using the same scale, plot the readings for gasoline on the same sheet of coördinate paper, and draw the graph showing the relation between depth and pressure in gasoline.

c. From your graph find (a) the pressure in centimeters of mercury at a depth of 40 or 50 cm. in gasoline, (b) at the same depth in water. Divide the pressure thus obtained for gasoline by that for water at the same depth. This result gives the density of gasoline, which is about .74. Why?

d. The density of mercury is 13.6. How would the pressure in mercury compare with the pressure in water at the same depth?

e. How would the height of a column of water compare with the height of a column of mercury which produced the same pressure?

f. How would the height of a column of gasoline compare with the height of a column of mercury which produced the same pressure?

g. Compare your answers to the last two questions with the results obtained by dividing depth by pressure in both cases. (See data.)

h. How does the pressure at the water taps vary on going from the basement to the second floor of your house?

i. Which of these locations would be the better for the installation of a water motor?

RECORD OF EXPERIMENT

(Record the readings in centimeters, estimating tenths of a millimeter)

WATER

Surface Reading	Open Arm of Manometer	Lower Arm of Manometer	Depth	Pressure in Cm. of Mercury	$\frac{\text{Depth}}{\text{Pressure}}$

GASOLINE

EXPERIMENT 5

WHAT IS THE PRESSURE OF THE GAS IN YOUR CITY GAS MAINS?

I. Density of gasoline used in manometer. (*a*) *By specific-gravity bottle.* Weigh any glass-stoppered bottle of about 200 cc. capacity (or, instead, a specific-gravity bottle).

Fill with water and weigh.

Rinse with a little gasoline, then fill with gasoline and weigh.

Divide the weight of the gasoline alone by the weight of the water alone to get the specific gravity of gasoline; that is, the ratio of the weight of gasoline to the weight of an equal volume of water.

This is numerically equal to the density of gasoline in grams per cubic centimeter, since 1 cc. of water weighs 1 g.

(*b*) *By balancing columns.* Bend a piece of glass tubing from 5 to 10 mm. in diameter and about 2 m. long, as shown in Fig. 11.

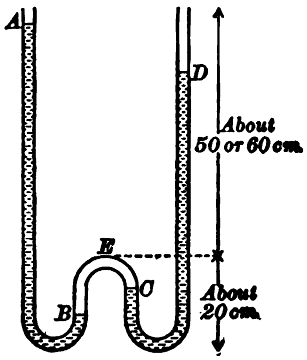


FIG. 11

Pour gasoline into the left arm to a depth of 10 or 15 cm. Then pour water into the right arm until the level at C is 3 or 4 cm. below the bend at E.

Then pour gasoline again into the left arm until the level at B is 3 or 4 cm. below the bend at E.

Repeat these operations until the left tube is nearly filled with gasoline. (It is unnecessary to have any two of the surfaces at the same level when ready for use.)

The pressure on the confined air in the bend E is equal to the pressure due to the column of gasoline $\overline{AB}$ + atmospheric pressure and is also equal to the pressure due to the column of water $\overline{CD}$ + atmospheric pressure.

Hence the pressure due to the column $\overline{AB}$ equals the pressure due to the column $\overline{CD}$, or

$$\overline{AB} \cdot d_g = \overline{CD} \cdot d_w = \overline{CD} \cdot 1$$

where d_g and d_w refer to the densities of gasoline and water respectively.

With a meter stick measure $\overline{AB}$ and $\overline{CD}$ and compute the density of gasoline.

II. Measurement of pressure in gas mains. With a Y or T connector attach the manometers of Fig. 12 to a gas cock.

Open the gas cock, and with a meter stick measure the height of A, B, C, and D above the table. Then, as before,

$$p = \overline{AB} \cdot d_g = \overline{CD} \cdot d_w$$

where p is the pressure in grams per square centimeter in the gas mains in excess of atmospheric pressure.

Using the average of the density of gasoline as found in I, (*a*) and I, (*b*), compute the pressure in the gas mains as given by each manometer.

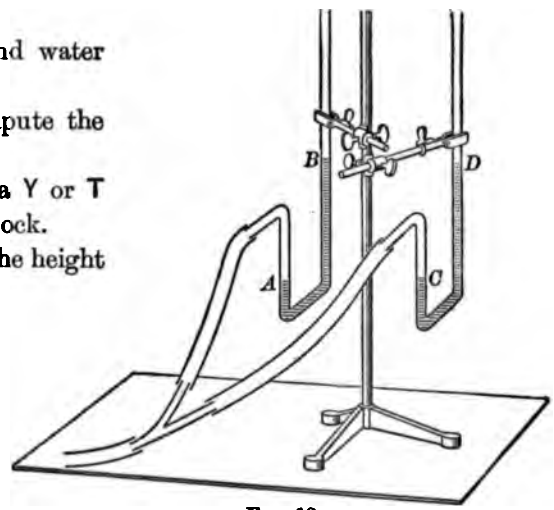


FIG. 12

Questions. ***a.*** If, in the apparatus of Fig. 11, mercury were used in the left-hand arm in place of gasoline, how would the vertical distance $\overline{DC}$ compare with the vertical distance $\overline{AB}$?

b. If the manometer tubes of Fig. 12 had had different diameters, would the result have been different? State reasons.

c. Gas plants use water manometers at distributing stations, and in this country the pressure is usually read in inches of water. What is meant then by a gas pressure of 7 in.?

EXPERIMENT 5 (*Continued*)

RECORD OF EXPERIMENT

I. Density of gasoline

(*a*) Weight of bottle = ... g.

Weight of bottle + water = ... g.

Weight of bottle + gasoline = ... g.

∴ weight of water alone = ... g.

∴ weight of gasoline alone = ... g.

∴ density of gasoline = ... g. per cc.

(*b*) From table to A = ... cm.

From table to B = ... cm. ∴ $\overline{AB}$ = ... cm.

From table to C = ... cm.

From table to D = ... cm. ∴ $\overline{CD}$ = ... cm.

$\overline{AB} \cdot d_g = \overline{CD} \cdot 1$ or (..........................) (d_g) = (..........................)

∴ density of gasoline = ... g. per cc.

∴ average density in (*a*) and (*b*) = $\frac{(\ldots\ldots) + (\ldots\ldots)}{2}$ = ... g. per cc.

II. Pressure in gas mains

Gasoline Manometer		Water Manometer	
From table to A =	.... cm.	From table to C =	.... cm.
From table to B =	.... cm.	From table to D =	.... cm.
∴ $\overline{AB}$ =	.... cm.	∴ $\overline{CD}$ =	.... cm.
∴ $p = \overline{AB} \cdot d_g$ =	.... g. per sq. cm.	∴ $p = \overline{CD} \cdot 1$ =	.... g. per sq. cm.

EXPERIMENT 5 A

HOW MUCH LUNG-PRESSURE CAN YOU EXERT?

I. Density of mercury used in manometer. (*a*) *By specific-gravity bottle.* Weigh a glass-stoppered bottle of 25 or 50 cc. capacity.

Fill with mercury and weigh.

Fill with water and weigh.

Rinse the bottle with a little alcohol and then with a little ether to remove water which clings to the inside before putting it away.

Divide the weight of the mercury alone by the weight of the water alone to get the specific gravity of mercury; that is, the ratio of the weight of mercury to the weight of an equal volume of water.

This is numerically equal to the density of mercury in grams per cubic centimeter, since 1 cc. of water weighs 1 g.

(*b*) *By balancing columns.* Pour mercury to a depth of about 10 cm. into the left arm of the apparatus shown in Fig. 11.

Then pour water into the right arm till nearly filled.

The pressure on the confined air in the bend E is equal to the pressure due to the column of mercury $\overline{AB}$ + atmospheric pressure, and is also equal to the pressure due to the column of water $\overline{CD}$ + atmospheric pressure.

Hence the pressure due to the column $\overline{AB}$ equals the pressure due to the column $\overline{CD}$, or

$$\overline{AB} \cdot d_m = \overline{CD} \cdot d_w,$$

where d_m and d_w refer to the densities of mercury and water respectively.

With a meter stick, measure carefully the vertical distances $\overline{AB}$ and $\overline{CD}$ and compute from these measurements the density of mercury.

II. Measurement of lung-pressure. Arrange a pressure gauge, or manometer, as in Fig. 13.

Record the level of the mercury in arm A of the manometer.

Then blow steadily for two or three seconds on the mouthpiece* M, and while doing so observe again the level of the mercury in arm A, reading both times at the upper edge of the curved mercury surface in the tube.

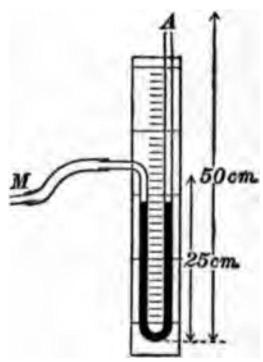


FIG. 13

Caution. Avoid taking a reading due to a quick, hard blow at M, as the inertia of the mercury in the tube will carry it higher than your lung-pressure will sustain it, and thus give an erroneous value of the pressure which you are able to exert with your lungs.

Evidently your lung-pressure expressed in centimeters of mercury is twice the difference between the two observed readings. Why? Let h represent this pressure in centimeters of mercury.

Compute the pressure in the different units suggested in the data record, using the density of mercury obtained in I, (*a*).

Questions. *a.* If the tube A were several times as large in diameter, would the same lung-pressure produce the same difference of level between the two sides of the manometer?

b. What would have been the value of h had you used water in the manometer? Why then was water not used?

c. What per cent is your lung-pressure of the average lung-pressure of the class?

* The mouthpiece M consists of a piece of glass tubing about 8 in. long with the ends rounded in a Bunsen burner. Several of these should be provided, and each should be sterilized by being placed in a beaker of boiling water for several minutes after use by a student.

EXPERIMENT 5 A (*Continued*)

RECORD OF EXPERIMENT

I. Density of mercury

(*a*) Weight of bottle = ... g.

Weight of bottle + mercury = ... g.

Weight of bottle + water = ... g.

∴ weight of mercury alone = ... g.

∴ weight of water alone = ... g.

∴ density of mercury = ... g. per cc.

(*b*) From table to A = ... cm.

From table to B = ... cm. ∴ $\overline{AB}$ = ... cm.

From table to C = ... cm.

From table to D = ... cm. ∴ $\overline{CD}$ = ... cm.

$\overline{AB} \cdot d_m = \overline{CD} \cdot d_w$, or (........................) (d_m) = (........................) $\cdot 1$

∴ density of mercury = ... g. per cc.

II. Lung-pressure

First level of mercury in A = ... cm.

Second level of mercury in A = ... cm.

Difference = ... cm. ∴ h = ... cm.

$p = h \cdot d$ = ... g. per sq. cm.

= .... g. per sq. in.

= .... lb. per sq. in.

= .... atmospheres

EXPERIMENT 6

ARCHIMEDES' PRINCIPLE AND THE DENSITY OF A SOLID

I. To test Archimedes' principle for immersed bodies. Remove the left pan from the balance and replace it by the counterpoise c (Fig. 14) which is made as nearly as possible of the same weight as the pan. Adjust the balance by means of the nut n until the pointer stands at the middle mark. Suspend an aluminum cylinder or any regular solid body of volume 50 cc. or more from the left arm of the balance and counterpoise accurately with weights in the opposite pan. Record this weight.

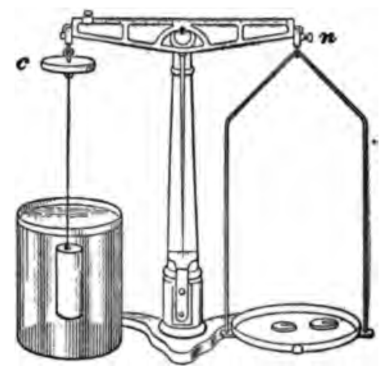


FIG. 14

Immerse the cylinder in water, as in Fig. 14. Carefully remove all air bubbles and weigh again. From these observations find the *loss of weight* which the body experiences when immersed in water. Measure the dimensions of the cylinder with the micrometer or vernier calipers, or simply by wrapping a fine silk thread about it, say thirty times, and measuring the length of the thread. Then compute the volume in cubic centimeters.

Compare the *loss of weight* obtained above with the *weight of the liquid displaced* by the body (that is, the volume of the body times the density of the liquid, which is in this case 1).

Weigh the cylinder when it is immersed in a beaker of gasoline and compare the loss of weight with the weight of the displaced liquid, taking the density of gasoline from the results of Exp. 5, I.

State in your notebook in your own words the principle which your experiment has shown to be true.

II. To find the density of a solid heavier than water by the loss of weight method. Since density is defined as $\frac{\text{mass}}{\text{volume}}$, it is obvious that the most direct way of determining the density of any regular solid is to find its mass by a weighing and its volume by direct measurement. But it would evidently be quite impossible to find in this way the density of an irregular body, like a lump of coal, because of the difficulty of measuring its volume. The principle discovered in I, however, furnishes a very simple way of finding this volume, since it is only necessary to find the loss of weight which the body experiences in water, in order to find the weight of an equal volume of water, and this is the same as the volume of the body, since the density of water is 1. We have, then,

$$\text{Density} = \frac{\text{weight in air}}{\text{loss of weight in water}}.$$

Without making any additional measurements, find the density of the body used in I, first, by dividing the weight in air by the volume as there computed from its dimensions, and second, by dividing the weight in air by the volume of the cylinder as found from the loss of weight in water.

Find in the latter way the density of some irregular body; for example, a brass weight.

Questions. *a.* Why will an egg sink in fresh water but float if a considerable amount of salt is dissolved in the water? Try the experiment at home.

b. Using your own weight in pounds, if you can just float in water with your nose out, compute your volume in cubic feet.

c. In the above experiments what became of the weight "lost"? If in doubt weigh a dish of wate then suspend the solid in it from a tripod, taking care that the solid does not touch the dish, and we again. Is the second weight of the dish more or less than the first, and how much? Why? (Note tha level of the water is raised when the solid is immersed.)

EXPERIMENT 6 (*Continued*)

RECORD OF EXPERIMENT

I. Archimedes' principle

	First Observation	Second Observation	Third Observation	Mean
Diameters	.... cm.	.... cm.	.... cm.	.... cm.

Length = ... cm.

∴ volume = ... cc.

Weight of cylinder in air = ... g.

Weight of cylinder in water = ... g.

Loss of weight in water = ... g.

Weight of displaced water = ... g.

Per cent of difference = ...

Weight of cylinder in gasoline = ... g.

Loss of weight in gasoline = ... g.

Weight of displaced gasoline = ... g.

Per cent of difference = ...

II. Density of solid used in I and of an irregular solid

(*a*) Density of aluminum = mass ÷ volume from dimensions = ...

(*b*) Density of aluminum = mass ÷ volume from loss of weight = ...

Per cent of difference = ...

Weight of brass body in air = ... g.

Weight in water = ... g.

∴ density of brass = ...

Accepted value = 8.4

EXPERIMENT 7

ARCHIMEDES' PRINCIPLE AND THE DENSITY OF A LIQUID

I. To test Archimedes' principle for floating bodies. Place in a deep vessel of water (see Fig. 9) a piece of thin-walled, cylindrical glass tubing about $\frac{3}{4}$ in. in diameter and 24 in. long, loaded with shot at the lower end (Fig. 15). (For the sake of convenience in II it is best to load the tube first in a vessel of gasoline until it sinks to within, say, 2 cm. of the top and then to transfer it without change in the load to the vessel of water.) Place a rubber band about the tube at the exact point to which it sinks in the water. Remove the tube from the water, wipe it dry, and then weigh it with the contained shot. Measure the diameter of the tube in four or five different places between the rubber band and the bottom, and measure the distance from the rubber band to the bottom. From these two measurements compute the volume, and therefore the weight, of the water displaced by the floating body.

FIG. 15

Infer from your results the general law of flotation, and state it in your notebook.

II. Density of a liquid by the principle of flotation. (*a*) *Constant-weight hydrometer.* Immerse the tube with its contents in a vessel of gasoline. Since the tube will float only when the weight of the displaced liquid is equal to the weight of the floating body, and since gasoline is less dense than water, the tube must sink to a greater depth in the lighter liquid than it did in water, for example, to some point C. Place a rubber band at this point, and then remove and measure the length immersed.

If l_1 is the length of the tube immersed in water and l_2 the length immersed in gasoline, then the density of gasoline must be l_1/l_2 times the density of water; for if A represents the area of the cross section of the tube, the weight of the water displaced by the tube is Al_1; and if d is the density of gasoline, the weight of the displaced gasoline is Al_2d; and since these weights are equal, being both equal to the weight of the floating body, we have $Al_2d = Al_1$; that is, $d = l_1/l_2$.

Test your result by means of a commercial constant-weight hydrometer (Fig. 16).

(*b*) *Constant-volume hydrometer.* Drop shot into a test tube which has been drawn out to the shape shown in Fig. 17 until, when immersed in gasoline, it sinks to the mark a on the narrow part of the stem. Remove the tube, dry, and weigh with the contained shot. Immerse in water, add more shot until the tube sinks to the same mark, remove, dry, and weigh again. The volume of the liquid displaced is the same in the two cases, and the weight of this volume is equal to the weight of the tube and its contents. The specific gravity, or density, of the gasoline may therefore be found at once, since the data are available for finding the weight of a given volume of gasoline and the weight of an equal volume of water. Compare the results with those obtained in (*a*).

State in your notebook what two general methods you have discovered for finding the densities of liquids.

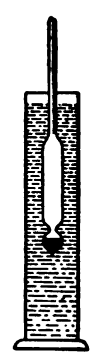


FIG. 16

FIG. 17

Questions. *a.* Can you see any reason why a constant-weight hydrometer made with a narrow stem (Fig. 16) is a much more accurate instrument for determining the densities of liquids than a cylindrical constant-weight hydrometer like that shown in Fig. 15?

b. If any convenient solid is weighed first in air, then in water, and then in some other liquid, for example, gasoline, the three weighings will furnish data for determining the density of gasoline. Write an explanation of this in your notebook, and compute the density of gasoline from the weighings of this sort which you made in Exp. 6.

c. If a tube, like that used in I, sank 36 cm. in water and 20 cm. in sulphuric acid, what was the density of the acid? How far would the same tube sink in a salt solution of density 1.125?

EXPERIMENT 6 (*Continued*)

RECORD OF EXPERIMENT

I. Archimedes' principle

	First Observation	Second Observation	Third Observation	Mean
Diameters	.... cm.	.... cm.	.... cm.	.... cm.

Length = ... cm.

∴ volume = ... cc.

Weight of cylinder in air = ... g.

Weight of cylinder in water = ... g.

Loss of weight in water = ... g.

Weight of displaced water = ... g.

Per cent of difference = ...

Weight of cylinder in gasoline = ... g.

Loss of weight in gasoline = ... g.

Weight of displaced gasoline = ... g.

Per cent of difference = ...

II. Density of solid used in I and of an irregular solid

(*a*) Density of aluminum = mass ÷ volume from dimensions = ...

(*b*) Density of aluminum = mass ÷ volume from loss of weight = ...

Per cent of difference = ...

Weight of brass body in air = ... g.

Weight in water = ... g.

∴ density of brass = ...

Accepted value = 8.4

EXPERIMENT 7

ARCHIMEDES' PRINCIPLE AND THE DENSITY OF A LIQUID

I. To test Archimedes' principle for floating bodies. Place in a deep vessel of water (see Fig. 9) a piece of thin-walled, cylindrical glass tubing about $\frac{3}{4}$ in. in diameter and 24 in. long, loaded with shot at the lower end (Fig. 15). (For the sake of convenience in II it is best to load the tube first in a vessel of gasoline until it sinks to within, say, 2 cm. of the top and then to transfer it without change in the load to the vessel of water.) Place a rubber band about the tube at the exact point to which it sinks in the water. Remove the tube from the water, wipe it dry, and then weigh it with the contained shot. Measure the diameter of the tube in four or five different places between the rubber band and the bottom, and measure the distance from the rubber band to the bottom. From these two measurements compute the volume, and therefore the weight, of the water displaced by the floating body.

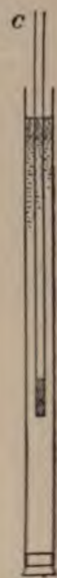


Fig. 15

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II. Density of a liquid by the principle of flotation. (*a*) *Constant-weight hydrometer.* Immerse the tube with its contents in a vessel of gasoline. Since the tube will float only when the weight of the displaced liquid is equal to the weight of the floating body, and since gasoline is less dense than water, the tube must sink to a greater depth in the lighter liquid than it did in water, for example, to some point C. Place a rubber band at this point, and then remove and measure the length immersed.

If l_1 is the length of the tube immersed in water and l_2 the length immersed in gasoline, then the density of gasoline must be l_1/l_2 times the density of water; for if A represents the area of the cross section of the tube, the weight of the water displaced by the tube is Al_1; and if d is the density of gasoline, the weight of the displaced gasoline is Al_2d; and since these weights are equal, being both equal to the weight of the floating body, we have $Al_2d = Al_1$; that is, $d = l_1/l_2$.

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(*b*) *Constant-volume hydrometer.* Drop shot into a test tube which has been drawn out to the shape shown in Fig. 17 until, when immersed in gasoline, it sinks to the mark a on the narrow part of the stem. Remove the tube, dry, and weigh with the contained shot. Immerse in water, add more shot until the tube sinks to the same mark, remove, dry, and weigh again. The volume of the liquid displaced is the same in the two cases, and the weight of this volume is equal to the weight of the tube and its contents. The specific gravity, or density, of the gasoline may therefore be found at once, since the data are available for finding the weight of a given volume of gasoline and the weight of an equal volume of water. Compare the results with those obtained in (*a*).

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Fig. 16

Fig. 17

Questions. ***a.*** Can you see any reason why a constant-weight hydrometer made with a narrow stem (Fig. 16) is a much more accurate instrument for determining the densities of liquids than a cylindrical constant-weight hydrometer like that shown in Fig. 15?

b. If any convenient solid is weighed first in air, then in water, and then in some other liquid, for example, gasoline, the three weighings will furnish data for determining the density of gasoline. Write an explanation of this in your notebook, and compute the density of gasoline from the weighings of this sort which you made in Exp. 6.

c. If a tube, like that used in I, sank 36 cm. in water and 20 cm. in sulphuric acid, what was the density of the aci[illegible] far would the same tube sink in a salt solution of density [illegible]

EXPERIMENT 6 (*Continued*)

RECORD OF EXPERIMENT

I. Archimedes' principle

	First Observation	Second Observation	Third Observation	Mean
Diameters	.... cm.	.... cm.	.... cm.	.... cm.

Length = ... cm.

∴ volume = ... cc.

Weight of cylinder in air = ... g.

Weight of cylinder in water = ... g.

Loss of weight in water = ... g.

Weight of displaced water = ... g.

Per cent of difference = ...

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Loss of weight in gasoline = ... g.

Weight of displaced gasoline = ... g.

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II. Density of solid used in I and of an irregular solid

(*a*) Density of aluminum = mass ÷ volume from dimensions = ...

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Per cent of difference = ...

Weight of brass body in air = ... g.

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∴ density of brass = ...

Accepted value = 8.4

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If l_1 is the length of the tube immersed in water and l_2 the length immersed in gasoline, then the density of gasoline must be l_1/l_2 times the density of water; for if A represents the area of the cross section of the tube, the weight of the water displaced by the tube is Al_1; and if d is the density of gasoline, the weight of the displaced gasoline is Al_2d; and since these weights are equal, being both equal to the weight of the floating body, we have $Al_2d = Al_1$; that is, $d = l_1/l_2$.

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State in your notebook what two general methods you have discovered for finding the densities of liquids.

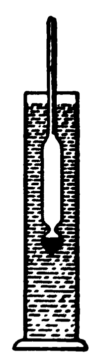


FIG. 16

FIG. 17

Questions. ***a.*** Can you see any reason why a constant-weight hydrometer made with a narrow stem (Fig. 16) is a much more accurate instrument for determining the densities of liquids than a cylindrical constant-weight hydrometer like that shown in Fig. 15?

b. If any convenient solid is weighed first in air, then in water, and then in some other liquid, for example, gasoline, the three weighings will furnish data for determining the density of gasoline. Write an explanation of this in your notebook, and compute the density of gasoline from the weighings of this sort which you made in Exp. 6.

c. If a tube, like that used in I, sank 36 cm. in water and 20 cm. in sulphuric acid, what was the density of the acid? How far would the same tube sink in a salt solution of density 1.125?

EXPERIMENT 7 (*Continued*)

RECORD OF EXPERIMENT

I. Archimedes' principle for floating bodies

First diameter = ... cm.

Second diameter = ... cm.

Third diameter = ... cm.

Fourth diameter = ... cm.

Mean diameter = ... cm.

Length immersed = ... cm.

Area of cross section = ... sq. cm.

Weight of displaced water = ... g.

Weight of tube and shot = ... g.

Per cent of difference = ...

II. (*a*) Constant-weight hydrometer

Length in water = ... cm.

Length in gasoline = ... cm.

∴ density of gasoline = ...

By commercial hydrometer = ...

(*b*) Constant-volume hydrometer

Weight in water = ... g.

Weight in gasoline = ... g.

∴ density of gasoline = ...

Difference between (*a*) and (*b*) = ... %

EXPERIMENT 8

DENSITY OF A SOLID LIGHTER THAN WATER

I. By weighing first in air and then when immersed in water with the aid of a sinker. If a body is lighter than water, the weight of an equal volume of water may be obtained with the aid of a sinker. Use a wooden block *B* (Fig. 18) which has been paraffined so as to prevent the absorption of water. Weigh the block alone in air and then with the sinker attached, the block being in air and the sinker *S* in water, as shown in the figure. Lastly, weigh when the block and the sinker are both under water. The difference between the second and the third weighings is evidently the buoyant effect of the water on the block alone, that is, it is the weight of the water displaced by the block, and hence it is also the volume of the block. From this difference and the weight of the block in air obtain the density of the block of wood used in this experiment.

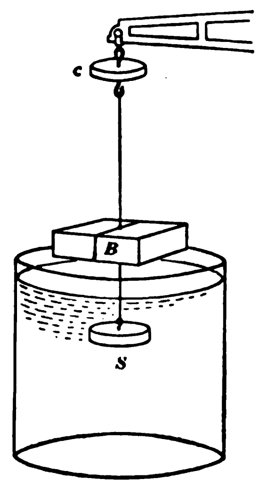


FIG. 18

Explain in your notebook how you calculated the density of wood, and why your method of procedure gives this density.

II. From the weight, length, breadth, and height of a block. Measure the three dimensions of the block with a meter stick held on edge, as in Fig. 2. From these measurements and the weight of the block, obtained in I, compute the density of the wood.

III. From the depth to which a block sinks in water. Wax a pin to the end of a metric rule *ab*, arranged as in Fig. 19, and take the reading of the point on this rule at which it meets the straightedge *CD* when the pin point just touches the corner *m* of the floating block. Then take the reading on *ab* when the pin point just touches the surface of the water, say, 1 cm. away from the edge of the block. The difference between these two readings subtracted from the height of the block would give the distance which the block sinks in the liquid if the surface of the block were accurately horizontal. In order to obtain as accurate a value as possible for this distance, repeat the measurements at each corner of the block, and take a mean of these four differences. From this mean difference find the distance h' which the block sinks in water. Then, from h' and the height h of the block compute its density d from the relation

$$d = \frac{h'}{h}.$$

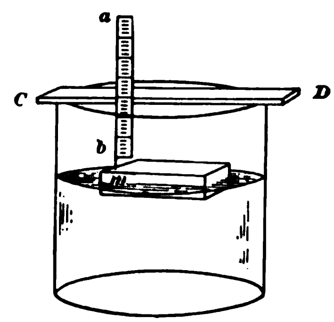


FIG. 19

Questions. *a.* Prove in your notebook that the above equation for the density of the block, namely, $d = \frac{h'}{h}$, follows at once from the statement of Archimedes' principle as applied to floating bodies; namely, "The weight of the floating body is equal to the weight of the liquid which it displaces." (Remember that weight = volume × density; so that, if A represents the area of the top of the block, the weight of the block is Ahd, while the weight of the displaced liquid is $Ah'd'$, d' in this case being 1.)

b. Can you see from your analysis any general relation which must always exist between the density of a body floating on water, the volume of the body, and the volume which is beneath the surface?

c. How much deeper will a 10 cm. cube of oak sink in water than a cube of pine of like dimensions, if the density of oak is .8 and that of pine .5?

d. Why are life preservers filled with cork instead of with pine?

e. Why is it unnecessary to know the density of the sinker *S* in this experiment?

EXPERIMENT 8 (*Continued*)

RECORD OF EXPERIMENT

I. Density by Archimedes' principle for a solid lighter than water

Weight of block alone in air = ... g.

Weight when block is in air and sinker in water = ... g.

Weight when both block and sinker are in water = ... g.

∴ density of wood = ...

II. From the weight, length, breadth, and height of the block

Length of block = ... cm. ∴ volume = ... cc.

Breadth of block = ... cm. ∴ density = ...

Height of block = ... cm. % of difference in I and II = ...

III. From the depth to which the block sinks in water

	First Corner	Second Corner	Third Corner	Fourth Corner
Reading with pin touching water =	.... cm.	.... cm.	.... cm.	.... cm
Reading with pin touching block =	.... cm.	.... cm.	.... cm.	.... cm
Differences =	.... cm.	.... cm.	.... cm.	.... cm

Mean difference = ..., h = ..., ∴ h' = ... ∴ d = ...

EXPERIMENT 9

THE RELATION BETWEEN THE PRESSURE AND THE VOLUME OF A GIVEN MASS OF GAS AT CONSTANT TEMPERATURE

I. Verification of Boyle's law. The quantity of air whose pressure and volume are to be varied is confined by the thread of mercury AB in one end BC (Fig. 20) of a glass tube about 1 m. long and of uniform bore 1 mm. in diameter. Since the cross section of the tube is uniform, the volume of the confined air is proportional to the length of BC.

With the tube vertical, closed end C down, the pressure on the confined air is atmospheric pressure plus the pressure due to the thread of mercury. Both of these pressures are in centimeters of mercury and therefore may be added.

(*a*) Read the barometer in centimeters.

Measure AB in centimeters and add to the barometer reading for the first pressure P_1.

Measure BC in centimeters and call this length the first volume V_1.

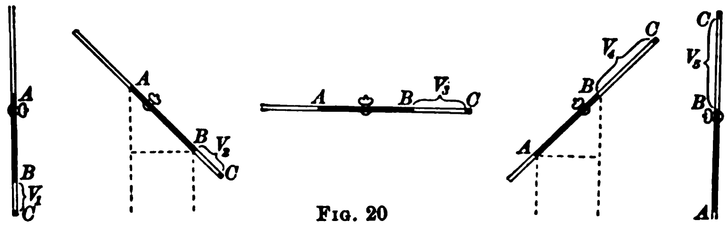


FIG. 20

(*b*) Rotate the tube approximately 45°. Now the pressure due to the thread of mercury AB is the vertical height of AB.

Measure the height of A, and of B, above the table and take the difference to get the vertical height of AB. Add this difference to the barometer reading to obtain P_2. Measure BC, as before, to get V_2.

(*c*) In the third, or horizontal, position the mercury thread neither increases nor decreases the pressure on the confined air, which is, therefore, at atmospheric pressure. Measure BC to get V_3.

(*d*) Rotate the tube approximately 45°, closed end C up. The vertical height of AB must now be subtracted from the barometer reading to obtain P_4. Why? Measure BC to get V_4.

(*e*) Take measurements with the tube vertical, closed end up.

II. Algebraic statement of an inverse proportion; for example, Boyle's law. (*a*) Note that the difference between any PV and the mean PV is seldom more than 2%. Then we may infer, barring errors, that

$$P_1V_1 = P_2V_2 = P_3V_3, \text{ etc., or, more simply, } PV = \text{constant.}$$

Thus we see that as P decreases, V must increase if the product remains constant, that is, P is inversely proportional to V, and the equation $PV =$ constant represents an inverse proportion.

(*b*) What relation do you note from your data between V_2/V_1 and P_1/P_2, etc.?

This is another way of stating an inverse proportion.

III. Graphical representation of an inverse proportion. (*a*) Using the equation $PV =$ constant, where this constant is the mean PV, compute the pressures which would correspond to two, three, and four times the greatest measured volume.

(*b*) Compute the volumes which would correspond to two, three, and four times the greatest observed pressure.

(*c*) Plot these six pressures and the corresponding volumes, together with the five pressures and volumes you obtained experimentally, representing pressures as horizontal distances and volumes as vertical distances. The smooth curve drawn through these points is called a hyperbola.

Questions. ***a.*** What relation exists between the pressure and the volume of a mass of gas at the constant temperature?

b. Give two equations showing this relationship.

c. What is the name of a curve which represents an inverse proportion?

EXPERIMENT 9 (*Continued*)

RECORD OF EXPERIMENT

Position of Tube	Volume of Confined Air (*BC*)	Height of *A* above Table	Height of *B* above Table	Difference (Vertical Height of *AB*)	Barometer Reading	Pressure	Pressure times Volume	Difference from Mean *PV*
(*a*)								
(*b*)								
(*c*)								
(*d*)								
(*e*)								

Compute the ratios below, giving three significant figures. Mean $PV =$ .... = constant.

V_2/V_1 = ... V_3/V_1 = ... V_4/V_1 = ... V_5/V_1 = ...

P_1/P_2 = ... P_1/P_3 = ... P_1/P_4 = ... P_1/P_5 = ...

Difference = ... Difference = ... Difference = ... Difference = ...

EXPERIMENT 9 A

TO FIND THE WEIGHT OF AIR IN ONE CUBIC CENTIMETER, IN ONE LITER, IN ONE CUBIC METER, AND IN THE LABORATORY *

(*a*) Attach a piece of rubber tubing and a pinchcock to a bottle † of about 2-liter capacity. Weigh the bottle and attachments to hundredths of a gram.

(*b*) With an air pump exhaust as much of the air from the bottle as you can by pumping moderately for two or three minutes, close the pinchcock tightly, and again weigh.

(*c*) Place the bottle and tubing neck end down in a large vessel of water at room temperature, open the pinchcock, and let the water in to take the place of the exhausted air. Push the bottle down into the vessel of water until the water in the bottle is just level with the water outside and then close the pinchcock. Remove the bottle, wipe off the water, and weigh the bottle, attachments, and water.

(*d*) Measure the length, width, and height of the laboratory in meters. Compute the quantities indicated in the record of the experiment.

(*e*) Take the temperature of the room and the barometer reading for the sake of the use they will be in answering some of the questions.

Questions. ***a.*** In (*c*) just before closing the pinchcock what was the pressure of the air remaining in the bottle in centimeters of mercury?

b. From the weight of 1 cc. of air which you obtained and the barometer reading, with the aid of Boyle's law compute the weight of 1 cc. at 76 cm. pressure, at the temperature of the laboratory.

c. The density of air at 76 cm. pressure, containing some moisture, is about .00122 at 15° C. or 59° F., .00120 at 20° C. or 68° F., .00118 at 25° C. or 77° F., and .00116 at 30° C. or 86° F. From these values find by interpolation the density of air at 76 cm. pressure, at the temperature of the laboratory. By what per cent does your value in ***c*** differ from this value?

d. About how deep would mercury have to be if it covered the whole of the earth to a uniform depth to have the same weight as all the air surrounding the earth?

RECORD OF EXPERIMENT

(*a*) Weight of bottle = ... g.
(*b*) Weight of bottle (exhausted) = ... g.
} ∴ weight of air exhausted = ... g.

(*c*) Weight of bottle and water = ... g. { ∴ volume of air exhausted (*c*–*b*) at atmospheric pressure } = ... cc.

(*d*) Length of laboratory = ... m., width = ... m., height = ... m.
∴ volume = ... cu. m.

(*e*) Temperature of room = ... °C., or .... °F., barometer reading = ... cm.

Weight of 1 cc. of air (density) = ..., weight of 1 liter of air = ... g.

Weight of 1 cu. m. of air = ... kg.

Weight of air in laboratory = ... kg. = ... lb.

From question ***b*** density = ... g. per cc.
From question ***c*** density = ... g. per cc.
} Per cent of difference = ...

* On account of the very considerable work involved in preparing a large number of air-tight bottles for this experiment and drying them after use before they are in readiness for another section, unless an ample number of spheres with good stopcocks are available, the authors would suggest that this experiment be performed but once, by the teacher and class together, rather than by each pupil.

† A hollow metal sphere with stopcock may be used without the tubing. All joints in either case should be made air-tight with vaseline, and the volume of the bottle or sphere should have been previously determined and marked upon it.

EXPERIMENT 10

THE MOLECULAR CONSTITUTION OF MATTER

(*a*) Fill a long, narrow test tube or, better, the hydrometer tube of Fig. 15 about half full of water.

(*b*) Then, to prevent mixing, incline the tube as much as possible while you carefully pour in alcohol till the tube is filled. If the alcohol has been poured into the tube with sufficient care, you should be able to observe a distinct surface of demarcation separating the two liquids.

(*c*) Place the thumb tightly over the top of the tube and slowly invert, and at the same time observe carefully what takes place.

(*d*) Keeping the thumb pressed tightly against the end of the tube, invert and restore it to its original position several times, until the liquids are thoroughly mixed. During this inverting process has your thumb been drawn into or pressed into the tube?

Questions. ***a.*** Will the combined volume of given volumes of water and alcohol be the sum of the separate volumes?

b. Will a bushel basket full of baseballs and a bushel basket full of small marbles fill two bushel baskets when thoroughly mixed?

c. How do you account for the combined volume of the alcohol and water being less after they are mixed?

EXPERIMENT 10 A

COOLING BY EVAPORATION; SATURATION; DEW POINT FREEZING BY EVAPORATION

I. Cooling by evaporation. Let three 4-oz. bottles, the first half-full of ether, the second half-full of alcohol, and the third half-full of water, be provided. The bottles should be closed with small corks and should have been standing in the room long enough to acquire room temperature.

(*a*) Swing a thermometer in the air for a minute and then record the temperature of the room.

(*b*) Insert the thermometer in the ether bottle, and at the end of half a minute record the temperature of the ether. Take the reading while the bulb is in the liquid. In the same way take the temperature of the alcohol and of the water.

(*c*) From the bottles pour enough of each liquid into the evaporating dishes of Fig. 21 to cover the bulbs of the thermometers and about the same amount of ether into a test tube supported in a beaker or test-tube rack. Watch the thermometers ten or fifteen minutes and record the temperature of each. (Pins driven into a 4 × 4-in. block will prevent sliding and breaking of thermometers and make a convenient support.)

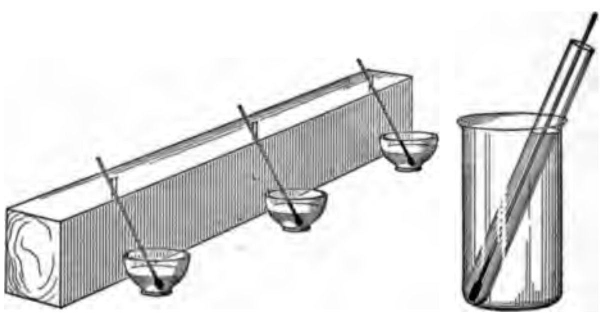


FIG. 21

(*d*) Put a drop of ether, of alcohol, and of water upon the hand and note the order of disappearance and also the order of the cooling sensations which they produce.

State in your notebook what effect your experiments have shown evaporation to have upon the temperature of the evaporating body. Explain, if you can, why the temperature of the ether in the test tube was different from that in the evaporating dish. Explain with the aid of this experiment and the answer to the first question why the ether in the evaporating dish had a lower temperature than the alcohol, and the alcohol a lower temperature than the water.

When a body is below room temperature it is continually receiving heat from the room. When the liquids in the evaporating dishes had reached a constant temperature, what relation existed between the amount of heat which they lost per second by evaporation and the amount which they received per second from the room?

II. Saturation. A space in which evaporation will no longer take place from the surface of a given liquid placed within the space is said to be *saturated* with the vapor of the liquid. This means simply that the space already contains as much of the vapor of the liquid as it is capable of holding at the given temperature.

(*a*) Cover the bulb of the thermometer with a bit of absorbent cotton, dip it into the bottle of ether, and then lift it so that the bulb and cotton are above the surface of the ether but still in the bottle. Watch the temperature for a minute or two and then record. Transfer the covered bulb from the bottle to the test tube and hold it there above the surface. After a minute or two record the temperature. Lift the covered bulb out into the air and record the temperature after it has become constant. What do you learn from this experiment regarding the temperature which a thermometer surrounded with a cloth soaked in a liquid will maintain in a space which is saturated with a vapor of the liquid? in a space which is partially saturated? in a space which is free from this vapor, that is, which is dry?

(*b*) Wrap some fresh cotton about the bulb of the thermometer, and dip it into the bottle of water; then remove the thermometer and swing it in the room until its reading becomes constant

Would this reading be any different if there were no water vapor already in the room? What would it be if the air were already saturated with water vapor? Can you see, then, how the difference between the readings of a thermometer whose bulb is kept dry and one whose bulb is kept moist gives us some information regarding the dryness of the atmosphere?

III. Dew point. The amount of vapor which a given space can hold is found to decrease rapidly as the temperature decreases. Hence, if we lower the temperature of a space which is already saturated with any vapor, a part of it condenses. If we lower the temperature of a space which is not saturated, but which contains some vapor, nothing happens until the temperature is reached at which the amount of vapor which already exists in the space is the amount which saturates it. Then condensation begins. *The temperature at which water vapor begins to condense out of the atmosphere as the temperature is lowered, is called the dew point.* It varies, of course, from day to day, depending upon the amount of water vapor in the atmosphere.

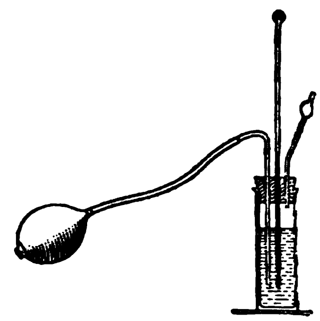


FIG. 22

(*a*) Fill the polished metal tube * of Fig. 22 two-thirds full of ether, and force air very gently through it by squeezing the bulb. This process facilitates cooling, since it increases enormously the evaporating surface, every bubble having a large surface through which evaporation can take place. The temperature existing within the tube when the first cloudiness begins to appear upon the polished surface is the dew point, for it is the temperature at which the layers of air in contact with the tube become saturated and begin to deposit their moisture. As soon as this cloudiness is noticed, take the reading of the thermometer, and then stop the current and notice the temperature at which the cloudiness disappears. Take pains in these experiments not to breathe upon the polished surface. Repeat the whole operation until the temperatures of appearance and disappearance do not differ by more than 1°. Take the mean of the two temperatures as the dew point.

$t°$ C.	P	$t°$ C.	P	$t°$ C.	P	$t°$ C.	P	$t°$ C.	P
− 10°	2.2	− 1°	4.2	8°	8.0	17°	14.4	26°	25.0
− 9°	2.3	0°	4.6	9°	8.5	18°	15.3	27°	26.5
− 8°	2.5	1°	4.9	10°	9.1	19°	16.3	28°	28.1
− 7°	2.7	2°	5.3	11°	9.8	20°	17.4	29°	29.7
− 6°	2.9	3°	5.7	12°	10.4	21°	18.5	30°	31.5
− 5°	3.2	4°	6.1	13°	11.1	22°	19.6	35°	41.8
− 4°	3.4	5°	6.5	14°	11.9	23°	20.9	40°	54.9
− 3°	3.7	6°	7.0	15°	12.7	24°	22.2	45°	71.4
− 2°	3.9	7°	7.5	16°	13.5	25°	23.5		

(*b*) From the dew point and the accompanying table find the *humidity* of the atmosphere. This is the ratio between the amount of moisture in the atmosphere at the time of the experiment and the total amount which it is capable of holding at the temperature of the room. It is found by dividing the pressure of saturated water vapor at the temperature of the dew point by the pressure of saturated water vapor at the temperature of the room (see table). †

IV. Freezing by evaporation. Place a few drops of water upon the table and set the polished metal tube containing ether upon it. Force air through the ether rapidly and see if you can freeze the tube to the table.

* This experiment can be performed almost as successfully by dropping bits of ice slowly into water contained in a polished vessel, and noting the temperature at which, with continual stirring, the cloud appears on the outside. If the dew point is below zero, salt should be added, bit by bit, to the iced water until the cloud appears.

† The table shows the pressure *P*, in millimeters of mercury, of water vapor saturated at temperature $t°$ C.

Questions. ***a.*** What effect does evaporation have on the temperature of a liquid?

b. In I, (*c*), why does not the temperature of the ether in the test tube fall as low as in the evaporating dish?

c. From the data of I, (*a*) and I, (*b*) decide whether evaporation is taking place at the surface of a liquid in a closed bottle.

d. See that all questions at end of I, II, and III are answered.

RECORD OF EXPERIMENT

	ETHER	ALCOHOL	WATER
I. (*a*) Temperature of room = ... °C.			
(*b*) Temperature of liquid in bottle			
(*c*) Temperature of liquid in evaporating dish			
Temperature of ether in test tube			
(*d*) Order of disappearance			
Order of cooling sensation produced			

II. (*a*) Temperature of cotton-covered bulb

In ether bottle = ... °C.

Above ether in bottle = ... °C.

Above ether in test tube = ... °C.

In still air = ... °C.

(*b*) Temperature of cotton-covered bulb, wet with water and swung = ... °C.

III. (*a*) Cloudiness appears at .... °C., disappears at .... °C. ∴ dew point = ... °C.

(*b*) Pressure of saturated vapor at dew point = ... mm. of mercury.

Pressure of saturated vapor at room temperature = ... mm. of mercury.

∴ relative humidity = ... %.

EXPERIMENT 11

RESULTANT OF TWO FORCES

I. Parallel forces. Support two spring balances* from nails, pegs, or tripod rods, as in Fig. 23 A, and so choose the distance between the supports that the meter stick ab is supported at, say, the 10-cm. and 90-cm. divisions.

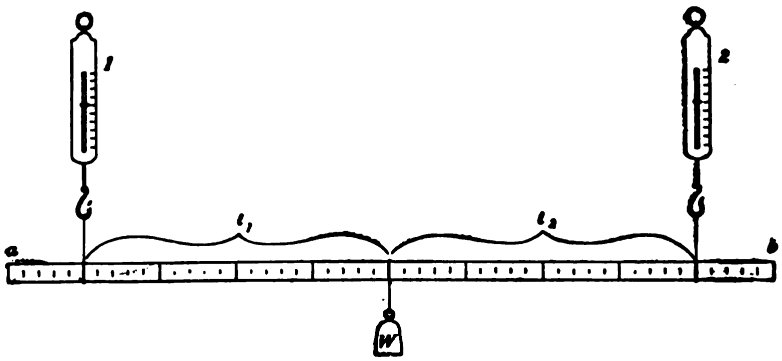


FIG. 23 A

Record the readings of the balances *1* and *2* when they support the meter stick without the weight W.

Hang from the 50-cm. mark a mass W which you have already weighed on one of the spring balances, and which is large enough to stretch it nearly to its limit.

Read the balances *1* and *2*, and call the differences between these readings and the initial readings F_1 and F_2 respectively.

Then take readings with W placed successively at the 40-cm., the 30-cm., and the 20-cm. mark.

Let l_1 and l_2 represent in each case the distance in centimeters from the point from which W is hung to *1* and *2* respectively.

Since the forces F_1, F_2, and W are in equilibrium, W is said to be the equilibrant of F_1 and F_2.

What single force would replace F_1 and F_2 and produce the same effect; that is, support W? This force is called the resultant of F_1 and F_2.

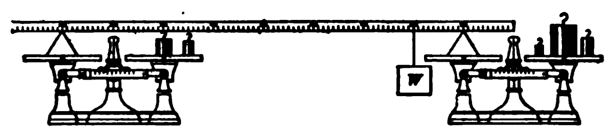


FIG. 23 B

State in your notebook what you learn from your results regarding, first, the magnitude of the resultant of two parallel forces; second, the product of either of two parallel forces by its distance from the resultant; third, the relation between the direction of the resultant of F_1 and F_2, and of W.

II. Concurrent forces. Fasten three spring balances to a small ring a by strings about 8 in. long and slip the rings of the balances over wooden pegs or nails in a board AB about 3 ft. square (Fig. 24). Choose such holes for the pegs that each balance is stretched to at least one half of its full range.

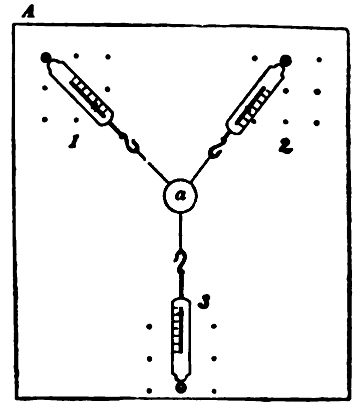


FIG. 24

Slip a page of your notebook beneath the central ring, fasten it down with thumb tacks or weights, and with a sharp-pointed pencil make a dot on the paper just at the center of the ring. Displace the ring and see that its center comes back exactly to the same position as at first. If this is not the case, the cause probably lies in the friction which exists between the balances and the board, a difficulty which may be remedied by raising the rings slightly on the pegs.

Make a dot exactly beneath each string and as far from a as possible; then take the three balance readings.

Unhook each balance from its peg and note the reading of the pointer as the balance lies flat on the table. If this reading is less than zero, add the suitable correction to the balance reading recorded on the paper: if it is more than zero, subtract the appropriate amount.

* If spring balances are not available, the apparatus may be arranged as in Fig. 23 B

Remove the paper and with great care draw a fine line from the central point through each of the three outside points. The direction of each line will represent the direction of the corresponding force.

Measure off a distance on each line which shall be proportional to the corresponding force, choosing any convenient scale; for example, if the forces are 700, 1000, and 1200 g., they may be conveniently represented by lines 7, 10, and 12 cm. long.

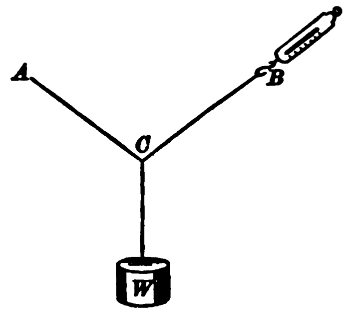


FIG. 25

With any two of these lines as sides complete a parallelogram, using a ruler and compasses to get the sides exactly parallel. Draw the diagonal of this parallelogram from the central point *a*, measure its length, and find the magnitude of the force which it represents. Thus, if the diagonal has a length of 134 mm., it would represent in the foregoing illustration a force of 1340 g. Compare with the reading of the third balance.

State in your notebook what you have proved to be true regarding both the magnitude and the direction of the resultant of two forces which meet at an angle.

Questions. *a.* If one singletree is attached 20 in. and the other 25 in. from the center-pin of a doubletree and the combined pull of the two horses is a force of 450 lb., with how many pounds of force is each horse pulling?

b. If a weight (Fig. 25) of 50 lb. is hung over the middle, *C*, of a wire *AB* whose breaking strength is 50 lb. and the tension at *B* is increased, show that the wire will break when the angle *ACB* becomes greater than 120°.

RECORD OF EXPERIMENT

I. Parallel forces

Initial reading of balance *1* = ... g., of balance *2* = ... g.

Weight *W* hung on meter stick = ... g.

	BALANCE *1*	BALANCE *2*	F_1	F_2	$F_1 + F_2$	$F_1 \times l_1$	$F_2 \times l_2$
W at 50 cm.							
W at 40 cm.							
W at 30 cm.							
W at 20 cm.							

II. Concurrent forces

Reading of balance *1* = ... Correction = ... ∴ F_1 = ...

Reading of balance *2* = ... Correction = ... ∴ F_2 = ...

Reading of balance *3* = ... Correction = ... ∴ F_3 = ...

Scale used 1 cm. = ... g.

Length of line 1 = ..., of line 2 = ...

Length of diagonal = ... ∴ resultant = ... ∴ error = ...%

EXPERIMENT 12

THE LAWS OF THE PENDULUM

I. To find whether or not the time of swing is different for different amplitudes and different weights. (*a*) Attach with sealing wax a small weight — preferably, a steel ball about $\frac{3}{4}$ in. in diameter — to a fine thread about 180 cm. long, and suspend it in a wooden clamp with square jaws, like that shown in Fig. 26.

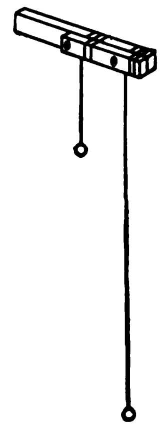


FIG. 26

Let a student, A, set his eye in some particular position, such that the thread is in line with some fixed mark or small object. Then let the pendulum be set into vibration through an arc 10 or 12 cm. long. Let a second student, B, keep his eye* on the second hand of a watch while A taps with his pencil upon the table at the instant of each passage of the pendulum past the fixed mark. When B is ready let him call "now" at the instant of some tap, and record the hour, minute, and second at which he called it; let A take up the count "one" at the instant of the next tap and continue up to one hundred. Let B record again the hour, minute, second, and, if possible, the fraction of a second, at which the count "one hundred" occurs.

Increase the amplitude of swing to about 30 cm. and again observe the time of one hundred vibrations exactly as before. Make another trial when the amplitude has been increased to 2 m. or more.

(*b*) Suspend another pendulum, which is of the same length from the support to the center of the bob but of quite different mass and material (for example, use for the bob a lead bullet), and see whether one pendulum gains at all upon the other when they are set going together through an arc of 30 or 40 cm.

So long as the amplitude of swing is small, do you find that the period depends upon it at all? What is the effect of a very large amplitude? What influence has the weight of the bob upon the period of a pendulum?

II. To find the relation between the lengths of two pendulums and their periods. Replace the last pendulum by a second one, which has a bob like the first, and adjust its length by slipping it through the clamp, the screw being only moderately tight, until it is just one fourth as long as the first pendulum. (The length of each is the distance from the bottom of the clamp to the top of the ball plus the radius of the ball.)

Using a small amplitude, take the time of 100 vibrations.

Make the pendulum one ninth of its original length and take the time of 100 vibrations.

With the aid of the ratios found, as indicated in the data record, state the law of lengths.

Questions. ***a.*** From the mean time of one vibration of the three trials made with the long pendulum using a small arc, and from the measured length of this pendulum, compute with the aid of the proportionality shown in II the length of a pendulum which will beat seconds.

b. It is shown in more advanced work in physics that the period of a pendulum t in terms of its length l and the value of the acceleration g due to gravity, is given by the equation $t = \pi\sqrt{\frac{l}{g}}$. Using the period and length of the first pendulum, compute g for your locality.

c. If the square of the period is directly proportional to the length of the pendulum, what kind of a graph would be obtained by plotting the squares of the periods for several pendulums as horizontal distances and the corresponding lengths as vertical distances? If time permits, verify your answer by plotting your own data in that way.

* If the second hand is observed through a reading glass of moderate power or the linen tester of Exp. 47, it will be found easy to estimate fifths of a second.

EXPERIMENT 12 (*Continued*)

RECORD OF EXPERIMENT

I. (*a*) Effect of amplitude

Arc 10 Cm.	Time of Beginning Count	Time of Ending Count	Total Time	Time of One Vibration
Sample trial	$10^h\ 45^m\ 10.4^s$	$10^h\ 47^m\ 25.0^s$	134.6^s	1.346^s
First trial	....	....	....	....
Second trial	....	....	....	....
Third trial	....	....	....	....
			Mean =	....
Arc 30 Cm.				
First trial	....	....	....	....
Second trial	....	....	....	....
			Mean =	....
Arc 200 Cm.				
First trial	....	....	....	....

(*b*) Effect of different weight

II. Relation between lengths and periods

Length of pendulums, No. 1 = ... cm., No. 2 = ... cm., No. 3 = ... cm.

Period of pendulums, No. 1 = ... sec., No. 2 = ... sec., No. 3 = ... sec.

$\frac{\text{Length No. 1}}{\text{Length No. 2}} = 4, \left(\frac{\text{Period No. 1}}{\text{Period No. 2}}\right)^2 =$ .... $\frac{\text{Length No. 1}}{\text{Length No. 3}} = 9, \left(\frac{\text{Period No. 1}}{\text{Period No. 3}}\right)^2 =$ ....

EXPERIMENT 13

RELATION BETWEEN FORCE ACTING UPON AN ELASTIC BODY AND THE DISPLACEMENT PRODUCED (HOOKE'S LAW)

I. Stretching. Set up a steel spring S and a mirror-scale M, in the manner shown in Fig. 27.

Take the reading of the index upon the scale when only the weight holder hangs from the spring. In so doing place the eye so that the image of the tip of the pointer p, as seen in the mirror, is exactly in line with the tip of the pointer itself. Record the position at which the line of sight crosses the mirror scale, reading to the nearest tenth millimeter (this tenth-millimeter place being, of course, an estimate).

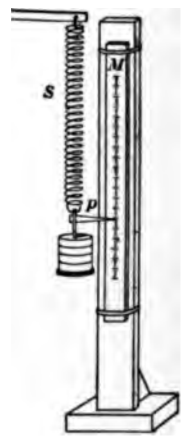


FIG. 27

Increase the weight upon the pan 100 g. at a time until it has reached a total of 400 g., and take the reading on the scale after each addition.

Then remove the weights 100 g. at a time and take the corresponding readings.

II. Bending. Set up the mirror scale behind the middle of a thin wooden or steel rod supported as in Fig. 28 and take again a set of readings like those in I, the index being now the point of a pin stuck with wax to the middle of the rod.

Finally, show graphically the relation between displacement and the force producing it. Let distances along OX, that is, to the right of the origin O of the graph, represent forces, and distances along OY, that is, above the origin O of the graph, represent displacements. Choose the scales used so that the graphs nearly fill the page of coördinate paper. Plot both sets of data on the same sheet.

With a straightedge draw two straight lines through the origin O, which shall come nearest to all the points. Why do these graphs* pass through the origin?

State in your own words in the notebook the law which the above study of two different sorts of elastic displacement has shown to exist between the distorting force F and the displacement D which this force produces.

State this result in the form of an equation.

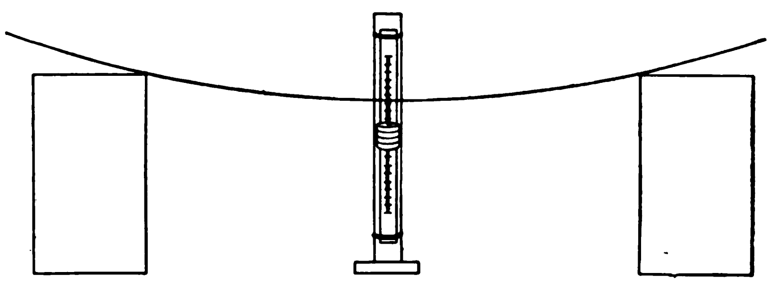


FIG. 28

III. Substitute for I. (The spring balance.) With a centimeter rule measure the distance from the zero to the 500-g. mark on the balance, from the zero to the 1000-g. mark, etc.

What relation do you find exists between the distance the spring in the balance is stretched and the stretching weight?

Plot the result of these observations, letting distances along OX represent the stretching forces, and distances along OY the corresponding elongations of the spring.

How would you proceed to graduate a spring balance that had no marks on it so that it would read in grams?

Would a spring balance graduated at sea level give correct readings if taken to the top of a high mountain? Why?

How would the readings of a spring balance be affected if it were taken from sea level at the equator to sea level at the north pole? Why?

* If the spring has an initial "set" due to the twist in the wire as the spring is coiled when made, the pan should be heavy enough to stretch it sufficiently to make a slight space between adjacent turns, otherwise the graph will not pass through the origin. Why?

EXPERIMENT 13 (*Continued*)

RECORD OF EXPERIMENT

I		II		III	
Spring	**Differences**	**Rod**	**Differences**	**Marks on Balance**	**Distance**
Pan reading = ...	....	....	....	0 to 500 g.	.... cm.
100-g. reading = ...	....	....	....	0 to 1000 g.	.... cm.
200-g. reading = ...	....	....	....	0 to 1500 g.	.... cm.
300-g. reading = ...	....	....	....	0 to 2000 g.	.... cm.
400-g. reading = ...	....	....	....		
300-g. reading = ...	....	....	....		
200-g. reading = ...	....	....	....		
100-g. reading = ...	....	....	....		
Pan reading = ...	....	....	....		

EXPERIMENT 14

THE PRESSURE COEFFICIENT OF EXPANSION OF A GAS AND THE MEANING OF ABSOLUTE ZERO

Experiments 14 and 14 A are intended as alternatives, the choice depending upon equipment. It is interesting, however, to have a part of the class perform 14 and a part 14 A, and then to let them compare results.

Charles found that when a body of gas is heated in a closed vessel the volume of which is kept constant, the pressure which the gas exerts against the walls of the vessel increases as the temperature rises. The ratio between the increase in pressure per degree and the pressure which the gas exerts at 0° C. is called the ***pressure coefficient of expansion of the gas.*** For example, if P_t represents the pressure at a temperature of $t°$ C. and P_0 the pressure at 0°C., then the increase in pressure has been $P_t - P_0$, the increase per degree has been $\frac{P_t - P_0}{t}$, and the pressure coefficient c is this increase divided by P_0. Thus,

$$c = \frac{P_t - P_0}{P_0 t}.$$

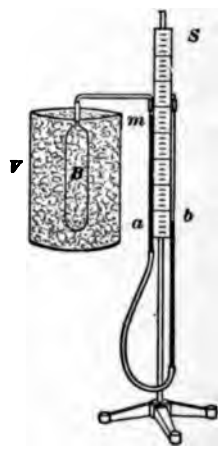


Fig. 29

To find this coefficient experimentally, first read the barometer. Then, before attaching the bulb B, adjust the arms a and b (Fig. 29) until the mercury in each stands, say, 5 cm. above the bottom of the scale S, the distance from the bottom of S to the point of attachment of the rubber tubing to the arm b being at least 30 cm. and the distance from the mercury surface in a to the scratch m on the tube a being about 4 cm.

Now introduce about 1 or 2 cc. of phosphorus pentoxide into B to keep the air in B perfectly dry; then attach B, as in the figure, with a bit of thick-walled gum-rubber tubing and pack wet snow or crushed ice about it in a vessel V until B is completely covered.

Raise the arm b until the mercury in a is just opposite the scratch m, tapping a gently with a pencil to prevent the mercury from sticking. Wait two or three minutes to make sure that the air in B has reached the temperature of the ice, and then adjust again to the scratch m and read on the scale S the levels in both a and b.

Put the bulb into the steam generator shown in Fig. 31, and boil the water. Adjust the arm b until the level in a is again at m; tap and again read the levels of the mercury in a and b.

Immediately after this reading lower the arm b to its first position, so that the mercury may not be drawn over into B as the bulb cools.

From your data compute c, as indicated in the data record.

State in your own way in your notebook what the "pressure coefficient of expansion c" means.

Questions. *a.* What per cent of error would have been introduced into your numerator, $P_{100} - P_0$, and therefore into your result, by an error of half a millimeter in this increase in pressure when the gas is heated?

b. If the boiling point of water on the day of your experiment were 99.5° instead of 100°, what per cent of error would you have introduced into your result by calling it 100°? On the whole is your result as accurate as you could have expected, in view of such sources of error as you can see?

c. If a gas at 0° C. is cooled at constant volume, and if the pressure decreases $\frac{1}{273}$ of what it was at 0° C. for each degree cooled, how many degrees would it have to be cooled to reduce the pressure to nothing?

d. At this temperature would the molecules be in motion? Explain what absolute zero means.

e. Show from your results in this experiment that when a gas is heated at constant volume, the pressure is directly proportional to the absolute temperature; that is, $\frac{P_1}{P_2} = \frac{t_1 + 273}{t_2 + 273} = \frac{T_1}{T_2}$ (Charles's law).

EXPERIMENT 14 (*Continued*)

RECORD OF EXPERIMENT

Barometer reading = ... cm.

Reading in *a* at 0° C. = ... cm. } Difference = ... cm.

Reading in *b* at 0° C. = ... cm. } $\therefore P_0$ = ... cm.

Reading in *a* at 100° C. = ... cm. } Difference = ... cm.

Reading in *b* at 100° C. = ... cm. } $\therefore P_{100}$ = ... cm.

$C = \dfrac{P_{100} - P_0}{100\,P_0}$ = ... $= \dfrac{1}{\text{.........}}$. **Accepted value** = .00367 = $\frac{1}{273}$. **Per cent of error** = ...

EXPERIMENT 14 A

THE VOLUME COEFFICIENT OF EXPANSION OF A GAS (GAY-LUSSAC'S LAW)

Gay-Lussac found that when a confined body of gas is kept under constant pressure and heated, its volume increased at the same rate at which its pressure increased when the volume was kept constant (see Exp. 14).

When a confined body of gas is kept under constant pressure and heated, it follows, from Boyle's law, that its volume must increase at the same rate at which its pressure would increase if the volume were kept constant. The ratio between the increase in volume per degree and the volume at 0° C. is called *the volume coefficient of expansion;* that is, if V_{100} and V_0 represent the volumes at 100° C. and 0° C. respectively, then the volume coefficient c is given by the equation

$$c = \frac{V_{100} - V_0}{100\ V_0}.$$

This coefficient may be defined as *the expansion at 0° C. per cubic centimeter per degree.* It should be the same as the pressure coefficient discussed above.

To find it experimentally, let a thread of dry air about 20–25 cm. long be confined by a mercury index 2 or 3 cm. long in a piece of barometer tubing which is sealed at one end and is about 40 cm. long.* (See Fig. 30.)

First measure carefully and record the length BC of the mercury index and the total length AD of the bore, allowing as best you can for the fact that the bore is not quite uniform very near the closed end. Then stand the tube upright, closed end down, in a battery jar, and pack wet snow about it up to the index. Tap the tube with a pencil, and, when the index remains constant, measure from A to the top B of the index. Remove the tube and push it through the hole in the cork which closes the steam generator of Figs. 31 and 41. After the steam has been issuing from the upper vent for a minute or two adjust the height of the tube in the cork so that the upper end of the index is just on a level with the top of the cork, and then measure from A to the top of the cork. Since the tube is of approximately uniform bore, you may take the difference between the last two measurements as $V_{100} - V_0$. From the first three readings find the length of the thread of air at 0° C. and call it V_0. Compute c from your data.

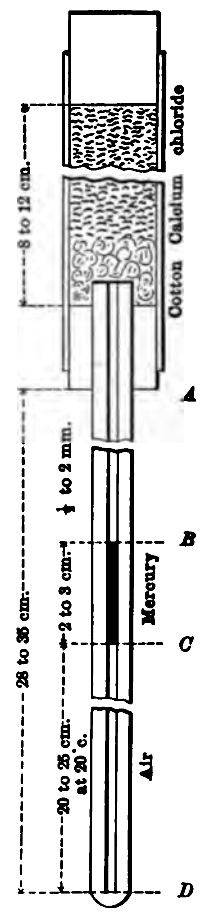


FIG. 30

Questions. *a.* Is your error larger than would be accounted for by an error of, say, .5 mm. in measuring $V_{100} - V_0$?

If so, it is probable either that the bore is not uniform or that the confined air is not thoroughly dry.

b. Show from the results of this experiment that when a gas is heated at constant pressure the volume is directly proportional to the absolute temperature; that is,

$$\frac{V_1}{V_2} = \frac{t_1 + 273}{t_2 + 273} = \frac{T_1}{T_2}.$$

c. If Exp. 9 (Boyle's law) was performed at 20° C., what would have been the value of the constant PV had the experiment been performed at 25° C.?

* To make such tubes, take barometer tubing of about 1.5-mm. bore, clean it with hot aqua regia or a hot solution of potassium bichromate in strong sulphuric acid, then rinse with distilled water, and dry by gently heating while a current of air passes first through a calcium-chloride drying tube and then through the barometer tube. Seal one end quickly in a Bunsen burner, and with a capillary funnel introduce the thread of mercury BC. Attach the cotton- and calcium chloride-tube to keep the inside of the tube dry, and the tube should work satisfactorily for months. If the drying tube is not used, moisture will work past the mercury thread as it moves back and forth.

RECORD OF EXPERIMENT

Length of index, BC = ... cm.

Length of bore, AD = ... cm.

From A to index at 0° C., AB_0 = ... cm.

From A to index at 100° C., AB_{100} = ... cm.

$V_{100} - V_0 = AB_0 - AB_{100}$ = ... cm.

$V_0 = AD - (AB_0 + BC)$ = ... cm.

$C = \frac{V_{100} - V_0}{100\ V_0}$ = ... $= \frac{1}{\text{.........}}$. Accepted value = .00367 = $\frac{1}{273}$. Per cent of error = ...

EXPERIMENT 15

COEFFICIENT OF EXPANSION OF BRASS

The linear coefficient of expansion of a solid is equal to that fractional part of its length which it increases when heated 1° C. The coefficient of expansion of brass is .0000187; this means that a foot of brass rod will increase .0000187 ft. in length when heated 1° C., or that 1 cm. will increase .0000187 cm. in length when heated 1° C., etc.

Thus, if l_2 represents the length at a temperature t_2, and l_1 at a temperature t_1, the increase in length per degree is $\frac{l_2 - l_1}{t_2 - t_1}$, and the fractional part which this is of the length is the linear coefficient of expansion k. Thus,

$$k = \frac{l_2 - l_1}{l_1 (t_2 - t_1)}.$$

A shallow transverse groove is filed at some point c (Fig. 31) near one end of a piece of brass tubing oc about a meter long and a centimeter in diameter.

Place this tube upon two wooden blocks A and B so that the groove rests upon a sharp metal edge attached to A while the other end is supported by a piece of glass or brass tubing b about 6 mm. in diameter, which in turn rests upon a smooth glass plate waxed to the top of B. To one end of the glass rod b a pointer p about 20 cm. long is attached by means of sealing wax. When the brass tube oc is heated, its expansion causes b to roll forward, and this produces a motion of the end of the pointer p over the mirror scale s.

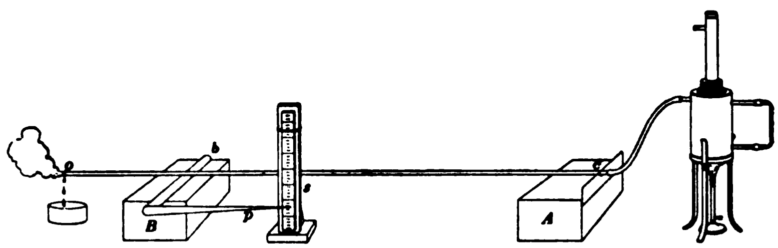


Fig. 31.

Attach the tube oc, as in the figure, to a steam boiler containing at first only cold water. Then insert a thermometer into the open end o of the brass tube oc.

Give the thermometer three or four minutes to take up the temperature of the tube; then read and record, and replace it in o.

Measure with a meter stick the distance between the knife-edge c and the middle of the rod b. Call this length l_1.

Record the position of the *tip* of the pointer upon the mirror scale s, estimating very carefully to tenths of a millimeter. Call this reading S_1. In taking this reading, sight (as always) across the image of the pointer and the pointer itself.

Apply heat to the boiler until steam passes *rapidly* through the tube. If the current of steam is sufficiently strong, the brass tube will not need a nonconducting covering. Nevertheless it is generally advisable before beginning the experiment to roll up a paper tube about $1\frac{1}{2}$ cm. in diameter, and to slip it over the tube between c and b in order to minimize heat losses.

After steam has been issuing from o for one or two minutes, take again the reading of the pointer p upon the scale s. Call this reading S_2.

Take the reading of the thermometer as it lies in the tube surrounded by the steam escaping from o.

Measure with the meter stick the length of the pointer p from its tip to the middle of b.

Measure with the micrometer caliper the diameter of b, taking readings upon at least three different diameters. This measurement should be made with an accuracy of at least .01 mm. If the calipers are not available, wrap a fine linen thread ten or twenty times around b, measure the length of the thread, and from this compute the diameter.

From Fig. 32 it will be seen that at any given instant the rod b is rotating about the lower end of its own vertical diameter, and that while the upper end of this diameter is moved a distance $(l_2 - l_1)$, the pointer p moves through the same angle over the distance $(S_2 - S_1)$. Then from similar triangles,

$$\frac{(l_2 - l_1)}{b} = \frac{(S_2 - S_1)}{p}, \text{ or } (l_2 - l_1) = \frac{b\,(S_2 - S_1)}{p}.$$

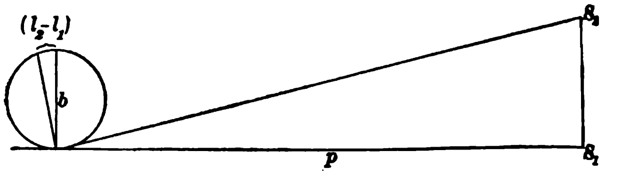


FIG. 32

Using this value of $(l_2 - l_1)$, compute k.

In calculating be sure that you express all length measurements in the same units; that is, all in centimeters.

Questions. *a.* The observational errors in this experiment amount to about 2%. Are your results as accurate as you should expect?

b. If a cube of brass 1 dm. on a side is heated 1° C., what will be its volume? what is the increase in volume? what is the volume coefficient of expansion of brass?

c. What relation do you see between the volume and the linear coefficients of expansion?

d. How are wagon tires put on a wooden wheel to make them very tight?

RECORD OF EXPERIMENT

Length of cb, or l_1 = ... cm.

First temperature of rod, t_1 = ... °C.
Second temperature of rod, t_2 = ... °C.
$\therefore (t_2 - t_1)$ = ... °C.

First reading on scale, S_1 = ... cm.
Second reading on scale, S_2 = ... cm.
$\therefore (S_2 - S_1)$ = ... cm.

Diameter of b = ... cm.
Length of pointer, p = ... cm.
$\therefore (l_2 - l_1)$ = ... cm.

$k = \frac{(l_2 - l_1)}{l_1 (t_2 - t_1)}$ = ... Accepted value = .0000187. Per cent of error = ...

EXPERIMENT 16

THE PRINCIPLE OF MOMENTS

Slip the meter bar AB through the sliding knife-edge support C (Fig. 33) until it will rest exactly horizontally when the knife-edge rests upon the glass surfaces of the wooden frame f. See that C is clamped firmly to the bar, read the position of the knife-edge on the bar, and then proceed as follows:

(*a*) By means of thread hang a 100-g. weight W_1 from a point near one end of the beam and find the point at which a 200-g. weight W_2 must be hung on the other side in order that the bar may rest again in an exactly horizontal position. Take the product of each weight by its distance from the fulcrum. What relation do you discover between these two moments? (The product of a force by the lever arm on which it acts is called the *moment* of the force.)

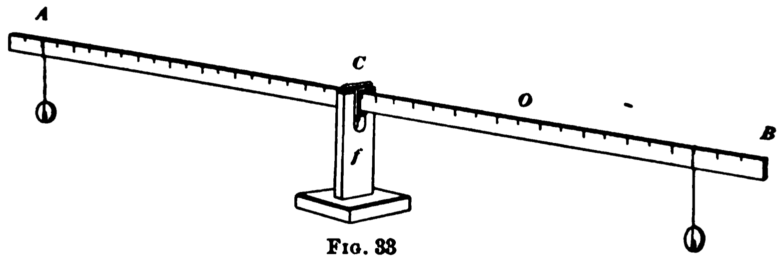


Fig. 33

(*b*) Hang two weights, say a 100-g. weight W_1 and a 50-g. weight W_2, at different points on the left side of the fulcrum and not too close to it, and then balance the lever by hanging a 200-g. weight W_3 at the proper point on the other side. Compare the sum of the moments of W_1 and W_2 with the moment of W_3.

(*c*) Hang some unknown weight X from a point near the left end at a distance l from the fulcrum, and balance it by a known weight W hung at the proper point on the other side. By applying the principle of moments, which you learned in (*a*) and (*b*), find the value of X. Weigh it on the balance and compare the two results.

(*d*) Hang from different points on the left side an unknown weight X and a known weight W_1, and balance by two known weights W_3 and W_4 placed at different points on the other side. Let l represent the distance of X from the fulcrum. Compute the weight of the unknown body and compare with the result of a direct weighing.

(*e*) Slip the knife-edge C to some point O such that OC is 10–15 cm., and clamp. Slip a known weight W, say 200 g., along between O and B until the beam rests horizontally when placed in the support. Then by applying the principle of moments find the weight of the beam on the assumption that the whole effect of the earth's attraction on the beam is equivalent to one single force equal to the whole weight of the beam and applied at the first position of the knife-edge; that is, at C, the center of gravity of the beam.

If X represents the weight of the beam, the principle of moments then gives

$$X \times \text{distance } CO = \text{known weight} \times \text{its distance from } O.$$

Compare the result with a direct weighing of the beam.

Questions. **a.** State what general conclusion you are able to draw from (*a*) and (*b*).

b. State what method the experiments have shown you for finding the weight of any body without the aid of a pair of scales.

c. Where does the result of (*e*) show that the total weight of a body, that is, the sum of the forces of gravity which act upon its particles, may be considered as concentrated?

d. A gate 14 × 5 ft., weighing 100 lb., is supported at the end by two hinges 4 ft. apart. What is the pull on the upper hinge in pounds? (Apply principle of moments; consider center of gravity of gate at the center of the gate.)

e. If a boy weighing 100 lb. stands on the end of the gate, what will then be the pull on the upper hinge?

EXPERIMENT 16 (*Continued*)

RECORD OF EXPERIMENT

(*a*) W_1 = ...; its lever arm = ...; its moment = ... }; per cent of difference = ...
W_2 = ...; its lever arm = ...; its moment = ...

(*b*) W_1 = ...; its lever arm = ...; its moment = ... }; sum = ...
W_2 = ...; its lever arm = ...; its moment = ...

W_3 = ...; its lever arm = ...; its moment = ...; { per cent of difference = ...

(*c*) W = ...; its lever arm = ...; its moment = ...
l = ...; $\therefore X$ = ...; by direct weighing X = ...

(*d*) W_3 = ...; its lever arm = ...; its moment = ... }; sum = ...
W_4 = ...; its lever arm = ...; its moment = ...
W_1 = ...; its lever arm = ...; its moment = ...
l = ...; $\therefore X$ = ...; by direct weighing X = ...

(*e*) Reading of knife-edge, at C = ...; at O = ...; $\therefore OC$ = ...
W = ...; its lever arm = ...; its moment = ...
$OC \times X$ = ...; $\therefore X$ = ...; by direct weighing X = ...

EXPERIMENT 17

THE PRINCIPLE OF WORK AND THE EFFICIENCY OF THE INCLINED PLANE

I. Principle of work. Since the work which a force accomplishes is equal to the product of the force by the distance through which it moves the point upon which it acts, the work done by a force F (Fig. 34) in moving a mass a distance l ($= on$) up the inclined plane on is equal to Fl. But the work done against gravity is equal to the product of the weight W which is moved times the vertical height h ($= mn$) through which W has been raised.

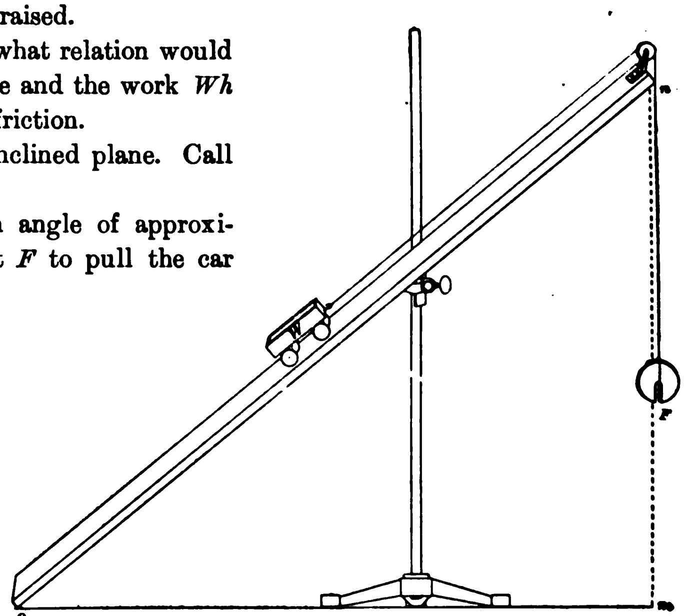


FIG. 34

The object of this experiment is to find what relation would exist between the work Fl of the acting force and the work Wh of the resisting force, in case there were no friction.

First weigh the car to be used on the inclined plane. Call this weight C.

Then with the inclined plane set at an angle of approximately 45°, hang enough 100-g. weights at F to pull the car up the incline.

Now add weights, from a set of weights, to the car until, with continued slight tapping on the plane, the car will just move slowly and uniformly down. Call the weights in the car w_1.

Remove weights until, with like tapping, the car moves just as uniformly up. Call the weights in the car w_2.

Take the mean of $C + w_1$ and $C + w_2$ as the weight W, which the force F would support on the plane if there were no friction.

Measure carefully with a meter stick the height of the plane mn and call it h. Similarly, measure the length of the plane on and call it l.

Set the inclined plane at an angle of about 30° and repeat all observations.

State in words the principle of work as proved by your data. Give also the algebraic statement of this principle for the inclined plane.

II. Efficiency of the inclined plane. The efficiency of any machine is the ratio of the useful work accomplished to the work done by the acting force; that is, efficiency $= \frac{\text{output}}{\text{input}}$. This is always less than 100 %, since, on account of friction, the output of all machines is less than the input.

In the case of the inclined plane, therefore, the efficiency in terms of the data already taken is given by the formula

$$\text{Efficiency} = \frac{(C + w_2)\,h}{Fl}.$$

Compute the efficiency for both trials, and record.

Questions. *a.* Two horses pull a loaded wagon weighing 3960 lb. up a 5 % grade (one that rises 1 ft. in 20 ft.), 1000 ft. long, in 5 min. If the force exerted by each horse is 165 lb., what is the efficiency?

b. In *a* how many foot pounds of work does each horse do per minute? This is the rate at which the average horse can work as found by James Watt (1736–1819).

c. In *a* if the load had been pulled in a car with ball-bearing wheels, on a steel track, how would the efficiency be affected?

d. State two things which affect the efficiency of an inclined plane.

EXPERIMENT 17 (*Continued*)

RECORD OF EXPERIMENT

I. Principle of work

Trial	C	w_1	w_2	W	h	F	l	$F \times l$	$W \times h$	Per cent of Difference
1										
2										

II. Efficiency

Trial	Output $(C + w_2)\,h$	Input $F \times l$	Efficiency
1			
2			

EXPERIMENT 17 A

THE USE OF PULLEYS TO CHANGE THE DIRECTION OF A FORCE, TO MULTIPLY FORCE, AND TO MULTIPLY SPEED

I. The single fixed pulley. With a piece of fish line or common cord hang a weight F' (the resistance) of about 1 or 2 kg. over the pulley, as shown in *I* (Fig. 35).

(*a*) Lift the weight by pulling uniformly and slowly down on the hook of the balance, taking its reading as you do so. Add to this reading the weight of the balance, to get F (down). In a similar way obtain F (up). The average of F (down) and F (up) gives what the force would be without friction. Denote this by F.

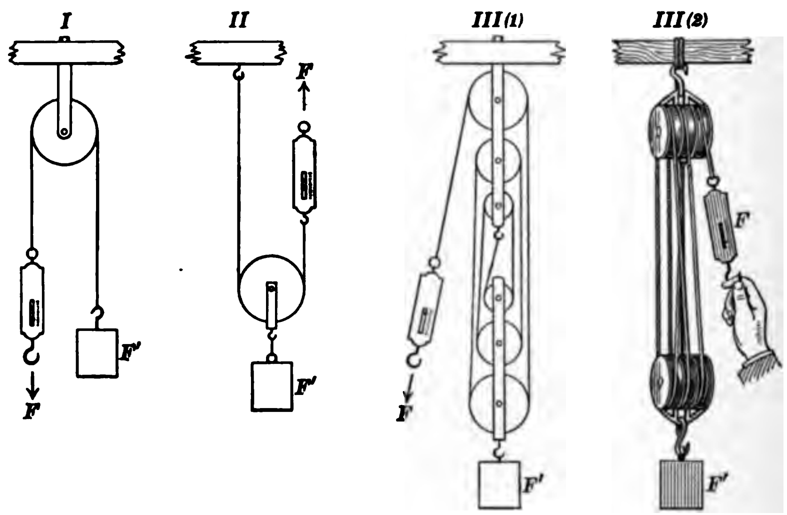


FIG. 35

(*b*) How far does the acting force F (the effort) move to lift the weight F' (the resistance) 10 cm.? These distances are called S and S' respectively.

(*c*) Compute $F \times S$ and $F' \times S'$; $F' \div F$ and $S \div S'$; and the efficiency, or $(F' \times S') \div (F \text{ (down)} \times S)$, that is, output $\div$ input.

(*d*) From the relation between $F \times S$ and $F' \times S'$ state the principle of work.

(*e*) The quotient $F' \div F$, that is, the ratio of the resistance to the effort, is called the mechanical advantage. State in your record two other ways of finding the mechanical advantage of a system of pulleys.

II. The single movable pulley. Take a set of observations similar to those of I, (*a*) and I, (*b*), using the pulley as arranged in *II* (Fig. 35). In this case, however, do not add the weight of the balance to the balance reading to get F (down) or F (up). Add the weight of the pulley to that of the mass lifted, to get F'.

III. Using a block and tackle similar to that shown in *III (1)* or *III (2)* of Fig. 35, make with its aid observations and computations like those in I.

IV. Hang a small weight, say 100 g., on the free end of the string of *III (1)* at F (Fig. 35), and with the hand pull down at F' instead of using the weight F'. Is the mechanical advantage now equal to the number of strands n leaving the movable pulley, or is it $\frac{1}{n}$?

With this arrangement is it force or speed that is multiplied?

Which is multiplied when the mechanical advantage is less than 1? Which is multiplied when the mechanical advantage is greater than 1?

Questions. ***a.*** Will it take more or less work to hoist a heavy weight to the top of a high building with a block and tackle than to lift it directly from above with a single rope attached? Why is the block and tackle used?

b. Draw a diagram in your book of a block and tackle whose mechanical advantage is 4; of one used so that its mechanical advantage is $\frac{1}{4}$.

c. Why is the efficiency of a pulley, or of a system of pulleys, always considerably lower than that of a lever or of a system of levers?

RECORD OF EXPERIMENT

Data

Weight of balance = ... g.

Weight of single pulley = ... g.

Weight of block and tackle = ... g.

	F (Down)	F (Up)	F	S	F'	S'
I						10 cm.
II						10 cm.
III						10 cm.

Calculations

	Principle of Work		Mechanical Advantage			Efficiency
	$F \times S$	$F' \times S'$	$F' \div F$	$S \div S'$	Number of Supporting Strands	$F'S' \div F$ (down) $\times S$
I						
II						*
III						

* In this case efficiency $= F'S' \div F$ (up) $\times S$, since the effort F acts up in overcoming the resistance F'.

EXPERIMENT 18

WHEN ONE CUBIC FOOT OF THE GAS PRODUCED BY YOUR HOME GAS COMPANY IS BURNED, HOW MUCH HEAT IS PRODUCED BY THE COMBUSTION?

First attach tube *A* of Fig. 36 to the gas main. Then, in order that you may be sure of complete combustion, adjust the Bunsen burner until, when burning low, the air supply is sufficient to make it burn with a rustling sound and a blue flame. When satisfactorily adjusted, record the reading of the water manometer *G*.

To fill the improvised gas meter of Fig. 36 remove the weight *W* from the top of the gas container, close stopcock *C′*, open *C*, and allow the gas to enter until the meter is filled.

Now attach tube *A* to *C′*, replace the weight *W*, and open *C′* until, with the burner lighted, the manometer *G* reads the same as before.

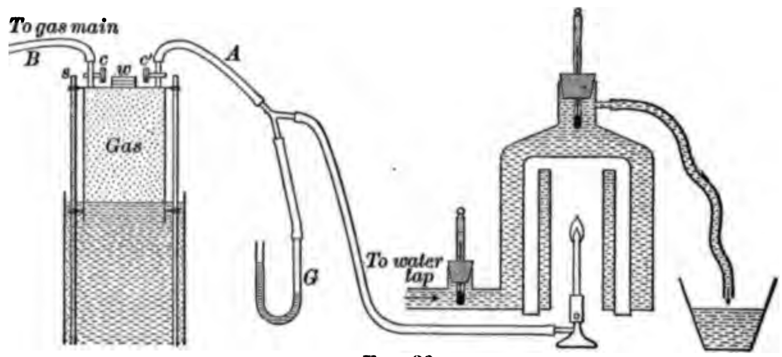


FIG. 36

Then place the burner under some form of Junker calorimeter and adjust the flow of water until the temperature of the outflowing water is about as much above the temperature of the room as that of the inflowing water is below the temperature of the room. As soon as the temperature of the outflowing water is constant and just as the gas meter reads some tenth of a cubic foot, as read on the scale *S*, note the reading of the gas meter and in the same instant place a pail under the outflow of the calorimeter.

Record the temperatures of both the inflowing and the outflowing water about every minute during the time of the experiment.

When 1 cu. ft. of gas has been consumed, remove the pail from under the outflow of the calorimeter, at the same instant reading the gas meter.

NOTE. It probably will be found more convenient to use less than a cubic foot of gas.

From the weight of the water and its rise in temperature as it passed through the calorimeter compute how much heat is produced by the combustion of 1 cu. ft. of the gas used.

Quantities of heat are measured in either British Thermal Units (B.T.U.) or in calories.

A British thermal unit is the amount of heat which passes into 1 lb. of water when its temperature rises 1° F., or the amount which passes out when its temperature falls 1° F. Hence the number of B.T.U. produced by the combustion of 1 cu. ft. of gas is given by the product of the number of pounds of water which pass through the calorimeter while 1 cu. ft. of gas is burned and the rise in temperature of the water in degrees Fahrenheit.

Similarly, a calorie is the amount of heat which passes into 1 g. of water when its temperature rises 1° C., or the amount which passes out when its temperature falls 1° C.

Since in 1 lb. there are 453.6 g., and since in 1° F. there are $\frac{5}{9}$° C., it follows that in 1 B.T.U. there are $\frac{5}{9}$ (453.6), or 252, calories. Hence if the weight of the water is taken in grams and its rise in temperature in degrees centigrade, the number of B.T.U. is given by

$$\text{B.T.U.} = \frac{(\text{weight of water in grams}) \times (\text{rise in temperature in degrees C.})}{252}.$$

Question. If 50% of the heat of combustion of the gas burned in a hot-water heater passes into the water, how much will it cost per month to heat daily 40 gal. of water (1 gal. = 8 lb.) from 50° F. to 180° F., the gas used being of the same quality as that used in this experiment, and the price being that charged by your home company?

RECORD OF EXPERIMENT

Reading of water manometer = ...

Reading of gas meter at start = ...
Reading of gas meter at end = ... } ∴ number of cubic feet of gas used = ...

Temperature of inflowing water = ...
Temperature of outflowing water = ... } ∴ rise in temperature of water = ...

Weight of pail = ...
Weight of pail plus water = ... } ∴ weight of water passed through calorimeter = ...

∴ number of B.T.U. produced = (weight of water in pounds) × (rise in temperature in degrees F.),

or number of B.T.U. produced $= \dfrac{\text{(weight of water in grams)} \times \text{(rise in temperature in degrees C.)}}{252}$.

Number of B.T.U. produced per cubic foot of gas consumed = ...

The grade of gas required by your city ordinance is such that the number of B.T.U. produced per cubic foot of gas = ...

EXPERIMENT 18 A

EFFICIENCY AND COST OF OPERATION OF COMMERCIAL GAS BURNERS AND KETTLES*

Attach one of the burners shown in Fig. 37 or any similar burner to the improvised gas meter of Fig. 36 or to an ordinary gas meter.

Place 1 or 2 qt. (1 qt. = 2 lb.) of water at about 15° C. (59° F.) in an ordinary teakettle.

With a thermometer take the temperature of the water, and when the gas meter reads some tenth of a cubic foot, place the kettle of water on the burner to heat.

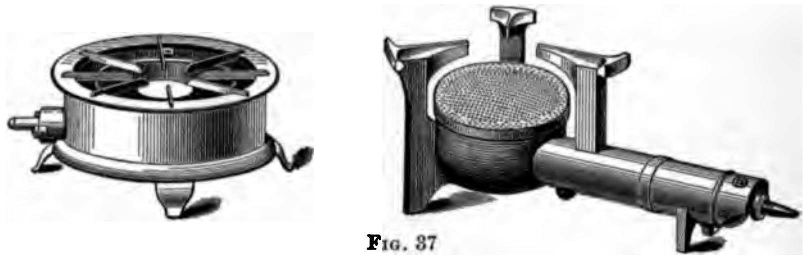


FIG. 37

Watch the thermometer, and as soon as the water reaches the boiling point turn off the gas from the burner and record the reading of the gas meter.

The "output," or useful heat obtained, expressed in B.T.U., = (number of pounds of water heated) × (rise in temperature of water in degrees Fahrenheit).

The "input," in B.T.U., = (number of cubic feet of gas used) × (number of B.T.U. produced by combustion of 1 cu. ft.). The number of B.T.U. produced by the combustion of 1 cu. ft. of gas is to be taken from Exp. 18 or obtained from the instructor.

Questions. *a.* At 80 cents per thousand cubic feet of gas, how much did it cost to boil the water for this experiment?

b. How many quarts of water could be raised from the same temperature to the boiling point for 1 cent?

c. In a similar way we shall later determine how many quarts of water can be boiled for 1 cent when the electric heater is used in place of the gas heater. We can then see which is the more efficient — in other words, the more economical; for in such work economy is the real test of efficiency.

RECORD OF EXPERIMENT

Weight of teakettle	=	∴ weight of water	= ....
Weight of teakettle + water	=		
Initial temperature of water	=	∴ rise in temperature of water	= ....
Final temperature of boiling water	=		
First reading of gas meter	=	∴ number of cubic feet of gas used	= ....
Second reading of gas meter	=		

Combined efficiency of burner and kettle $= \dfrac{\text{output in B.T.U.}}{\text{input in B.T.U.}}$

$$= \frac{\text{(number of pounds of water) (rise in temperature in degrees F.)}}{\text{(number of cubic feet of gas used) (number of B.T.U. produced by 1 cu. ft.)}} = \text{........................}\ \%.$$

* It is suggested that this experiment may be easily performed at home, using the gas-range burner and your own gas meter and kettle.

EXPERIMENT 19

TO FIND THE SPECIFIC HEAT OF A METAL; THAT IS, THE NUMBER OF CALORIES OF HEAT GIVEN UP BY ONE GRAM OF A METAL IN COOLING 1° C.

(*a*) Let three students work in a group while taking the data for this experiment. Let each student fill a boiler like that of Fig. 42 with water until it stands about half an inch high in the gauge, and then light a Bunsen burner under each boiler.

(*b*) Let student A place a dipper like that of Fig. 38 on the left pan of the scales, and balance it with weights on the right pan. Then add 1000 g. to the right pan and pour shot into the dipper until it again balances. (Do not try to get an exact balance, one or two shot, more or less, will make no appreciable difference.) Set the dipper inside the boiler and insert a thermometer through a loose-fitting cork or improvised cover, working it well down into the shot.

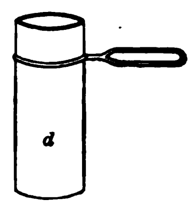


FIG. 38

(*c*) Let student B follow the instructions in (*b*), using 300 g. of iron pellets (or nails), and student C, using 150 g. of aluminum pellets (or aluminum punchings).

(*d*) Each student should now weigh or measure out 250 g. of cold water (12° C. or 15° C. below room temperature) and place it in the inner vessel, which is supported by its ring in the outer vessel of the calorimeter.

(*e*) With a glass rod or pencil stir the metals every four or five minutes until their temperatures become about 95° C. to 100° C.

(*f*) Let each student now read the temperature, on the same thermometer, of the cold water prepared by A, when it is about 9° C. or 10° C. below room temperature, see that all dew on the inner calorimeter, if any formed, is wiped off, record the temperature of the cold water and that of the shot, estimating tenths of a degree, and quickly pour the lead shot from the dipper into his calorimeter. Stir the mixture two minutes and record the temperature of the mixture, carefully estimating tenths of a degree.

(*g*) In the same way as in (*f*) the three students should take the data with the materials prepared by B and C, in each of these cases as before having the cold water 9° C. or 10° C. below room temperature just before pouring the hot metal into the calorimeter. Now spread out the metals used on cloths to dry.

(*h*) If we let S_m represent the number of calories of heat given up by 1 g. of metal in cooling 1° C., that is, its specific heat, then in cooling from the temperature of the metal, t_m, to the temperature of the mixture, t_{mix}, 1 g. of the metal would give up $(t_m - t_{mix})\ S_m$ calories; and the total mass of the metal, M_m, would give up $M_m\ (t_m - t_{mix})\ S_m$ calories. This must equal the heat received by the water and calorimeter according to the law of mixtures. (Heat lost by the body or bodies cooled = heat gained by the body or bodies warmed.)

Hence we have

$$\overbrace{M_m\,(t_m - t_{mix})\,S_m}^{\text{Calories out of Metal}} = \overbrace{M_w\,(t_{mix} - t_w)\,1}^{\text{Calories into Water}} + \overbrace{M_c\,(t_{mix} - t_w)\,.095}^{\text{Calories into Calorimeter*}},$$

where the subscript *m* refers to the metal used, "mix" to mixture, *c* to calorimeter, and *w* to water alone.

(*i*) Write out the numerical equation for each metal used and solve it for S_m. Explain what each of the equation represents.

State in your notebook what you understand to be represented by the quantity S_m which you found.†

* Take the specific heat of the calorimeter as .095.

† A further very interesting experiment which may be inserted for the benefit of those who have time and inclination for work is the following:

To find the temperature of a white-hot body. By means of a thin copper wire suspend from a support placed from 50 cm. to

EXPERIMENT 19 (*Continued*)

When the shot and the water were mixed, the changes in the temperature of each took place very rapidly at first, but very slowly as the temperature of each approached the final value. Can you see a reason, therefore, why it was advisable to choose the conditions so that the final temperature should be close to the temperature of the room? Remember in your answer that it was necessary to wait two or three minutes for the mixture to reach its final temperature, and that a body which is hotter than the room is always losing heat to the room, while one which is colder than the room is always gaining heat from it. It is these losses of heat by radiation which constitute the greatest difficulty in the way of accurate measurements by the method of mixtures.

RECORD OF EXPERIMENT

Metal	Weight of Metal M_m	Temperature of Metal t_m	Weight of Water M_w	Temperature of Water t_w	Temperature of Mixture t_{mix}	Weight of Calorimeter M_c	Experimental Value of S_m	Accepted Value of S_m	Per cent of Error
Lead									
Iron									
Aluminum									

Equation for lead:

Equation for iron:

Equation for aluminum:

100 cm. above the table a piece of copper rod about 2 cm. long and 12 mm. in diameter. Adjust the length of the suspension so that the copper hangs in the hottest part of a Bunsen flame (just above the inner cone).

Weigh a calorimeter of 300 cc. capacity; then fill it about half full of water whose temperature has been reduced 12° C. or 15° C. below that of the room, and weigh again. Then replace it in its jacket.

After the copper has been heating for about ten minutes take the temperature of the water very carefully (it should now be from 8° to 10° below the temperature of the room); then, all in the same second, remove the flame and lift the calorimeter so as to bring the white-hot copper to the bottom of the vessel of water.

Stir the water thoroughly for one or two minutes; then take the final temperature.

Weigh the copper rod and with it as much of the copper wire as was immersed.

Assuming that 0.95 calories (the specific heat of copper) came out of each gram of copper for each degree of fall in its temperature, calculate what was the temperature of the white-hot copper.

Duplicate conditions as nearly as possible and see how closely two observations will agree.

EXPERIMENT 20

THE MECHANICAL EQUIVALENT OF HEAT

The object of this experiment is to show that when a falling body strikes the earth, the kinetic energy of the moving mass is transformed into the energy of molecular vibrations, that is, into heat, and to find how many gram meters of mechanical energy must disappear in order to produce 1 calorie of heat. This quantity is called the *mechanical equivalent of heat.* It is obtained by finding the rise in the temperature of shot when it falls through a known height.

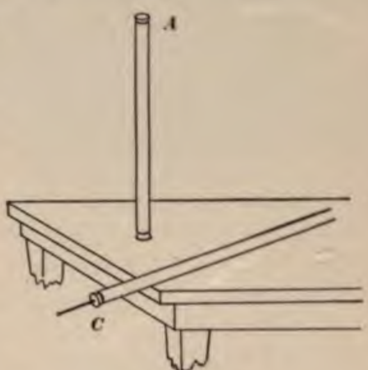


FIG. 39

Pour about 2 kg. of dry shot into a metal vessel and set it in a cool place, for example, in a bath of ice water, until its temperature is 5° C. or 6° C. below that of the room.

Pour this shot into a paper tube (Fig. 39) about a meter long and 5 or 6 cm. in diameter, made by rolling up a large number of turns of heavy brown paper and then securing them with glue and string. The tube should be closed with two tightly fitting corks.

Mix the shot very thoroughly by shaking the tube and by slowly inclining it so that the shot will run from end to end. In so doing, however, grasp the tube near the middle rather than at the ends, for it is desirable that the temperature of the ends be not influenced by the heat of the hands.

After inverting the tube in this way from five to ten times, remove the upper cork A and insert cork C (Fig. 39), through which passes a thermometer; then gradually incline the tube until all the shot has run down to the thermometer end and there completely surrounds the bulb.

Holding the tube inclined as in the figure, twist the thermometer around in the shot for about two minutes and then take the temperature. If this is more than 2° C. or 3° C. below the temperature of the room, continue the shaking and rolling of the shot from one end to the other until its temperature has risen to within about 3° C. of that of the room.

Record this temperature, quickly replace cork C by cork A, hold the tube upright, as in the figure, and turn it end for end, say, seventy times in rapid succession, placing the lower end on the table at each reversal, so that the falling shot may not force out the corks. At each reversal the potential energy acquired by the shot in being lifted the length of the tube is converted into kinetic energy in the descent, and this kinetic energy is all transformed into heat energy at the bottom. On account of the poor conductivity of cork and paper practically all of this heat goes into the shot and but an insignificant portion of it into the corks and the tube.

After the seventy reversals very quickly replace cork A by cork C and take as before the final temperature of the shot.

Remove cork C, set the tube on end, and measure the distance from the top of the shot to the position which was occupied by the bottom of cork A. This is the mean height through which the shot has fallen at each reversal.

The total number of gram meters of work which have been transformed into heat is the weight W of the shot $\times$ the height h of fall (expressed in meters) $\times$ 70. The number of calories of heat developed is the weight of the shot $W \times$ its specific heat (.0315) $\times$ the rise in temperature $(t_2 - t_1)$. Hence, if J represents the number of gram meters of energy in a calorie, we have

$$J \cdot W \times (t_2 - t_1) \times .0315 = 70 \cdot W \cdot h.$$

$$\therefore J = \frac{70\,h}{(t_2 - t_1)\,.0315}.$$

It will be noticed that the weight W of the shot cancels out; hence it need not be taken.

In the above directions the attempt is made to eliminate radiation and conduction losses by making the initial temperature of the shot about as far below the temperature of the room as the final temperature is to be above it. This is the usual way of eliminating radiation, when, as in this case, the change in temperature between the readings of the initial and final temperatures takes place rapidly and at a uniform rate.

Repeat the experiment several times if time permits.

What conclusions do you draw from your experiment?

The chief source of error in the experiment arises from the fact that the thermometer requires considerable time to come to the temperature of the shot. During all this time the shot is gaining or losing heat by conduction and radiation, so the temperature indicated may not be quite the mean temperature of the shot. This source of error is unavoidable.

Questions. ***a.*** Why did we attempt to have the initial temperature as far below the temperature of the room as the final temperature was above it?

b. If iron shot had been used instead of lead shot, would the rise in temperature be more or less than it was with lead shot?

c. Why is lead better for this experiment than any of the other metals?

RECORD OF EXPERIMENT

Illustrative data taken by a student.

	First Trial	Second Trial	Third Trial	
Temperature of room	= 18.5° C.	18.5° C.	18.5° C.	Mean value = 437 g. m.
Initial temperature	= 16.0° C.	17.1° C.	16.7° C.	
Final temperature	= 21.7° C.	22.6° C.	21.0° C.	Accepted value = 427 g. m.
Number of reversals	= 100	100	80	
Height of fall (h)	= .76 m.	.76 m.	.76 m.	
Mechanical equivalent	= 423 g. m.	439 g. m.	449 g. m.	Per cent of error = 2.4.

NOTE. The error in this experiment, even with careful work, may sometimes be as high as 10%.

EXPERIMENT 21

COOLING THROUGH CHANGE OF STATE

I. Solidification a heat-evolving process. The object of this experiment is to show that just as it requires an expenditure of heat energy to melt ice or any other crystalline substance, so when water or any liquid freezes, that is, changes back to the crystalline form, heat energy is given up to the surroundings.

Support vertically in a burette holder or other clamp a test tube in which enough loose crystals of acetamide have been placed to fill it about a third full. Then heat gently with a Bunsen burner until the crystals are all melted.* Slowly insert a thermometer into the liquid, but watch the thread all the time, and if it rises to within half an inch of the top of the bore, instantly remove the bulb from the liquid. *The thermometer will burst under the force of expansion of the mercury if the thread reaches the top of the bore.* If there is an expansion chamber at the top, this danger is of course avoided. If there is no expansion chamber, it will be safer to melt the acetamide by dipping the tube into boiling water rather than by applying the flame directly.

As soon as the liquid acetamide has cooled down to about 100° C., insert the thermometer in it permanently and, without touching further either the tube or the thermometer, watch carefully both the liquid and the thread of mercury as cooling takes place. The temperature may fall as low as 60° C. before crystallization begins. As soon as crystals begin to form, what sort of a temperature change do you observe? What conclusion do you draw from this observation? Watch the temperature for two or three minutes more and decide whether or not the temperature of a solidifying liquid remains constant during the process of solidification. Since it is giving up heat rapidly all this time, it must get it from some source. What must this source be?

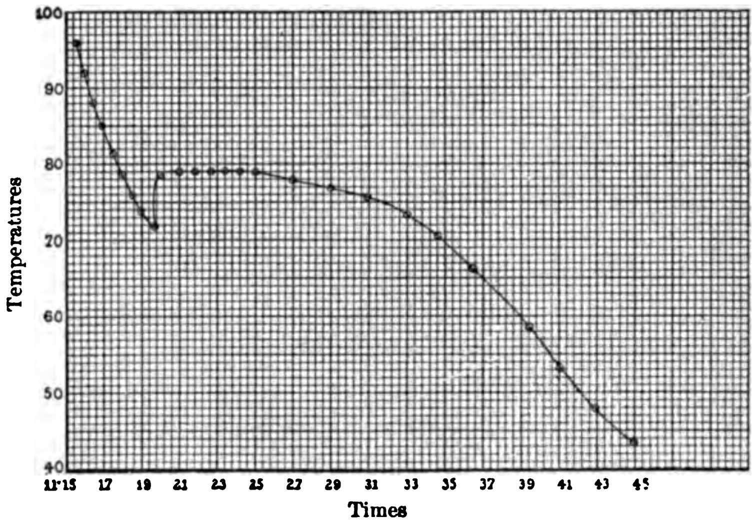


Fig. 40

II. The curve of cooling. Again raise the temperature to 100°C., taking the precautions mentioned above against breaking the thermometer. Record the temperature every half minute as the substance cools from about 100° C. to 45° C. Plot these observations in the manner shown in Fig. 40, temperatures being represented by vertical distances and times by horizontal distances. Thus, the observations plotted in the figure began at 11:15 A.M. and continued to 11:45 A.M. The curve shows that between 11:15 and 11:19.5 the temperature fell rapidly from 100° C. to 71.8° C., that it then rose suddenly to 79° C., remained there five minutes, and then fell slowly during the next twenty minutes from 79° C. to 43.5° C.

Write in your notebook a similar explanation of your own curve. Almost any substance, if kept very quiet and cooled through its freezing point, will show the phenomenon of *undercooling* exhibited here by the acetamide; that is, its temperature will fall a little below the freezing point before crystallization gets started. It will then rise suddenly to the freezing point and remain there until crystallization is practically complete. Why?

* If the acetamide has absorbed much moisture, boil it.

EXPERIMENT 21 (*Continued*)

If time permits, dip a test tube containing a little distilled water into a freezing mixture of salt water and ice, the temperature of which is, say, – 8° C., and see if water too will not show the same behavior. (The tube must be kept very quiet.) If you get the temperature down to – 2° C. or – 3° C., lift the test tube, stir, and observe the instant formation of the crystals of ice. If you wish to try a substance which does not undercool, treat a little naphthaline* precisely as you treated the acetamide.

RECORD OF EXPERIMENT

Time		Temperature
Hour	Minute	
etc.	etc.	etc.

* Naphthaline can be obtained at any drug store. Acetamide will have to be purchased at a chemical supply house.

EXPERIMENT 22

THE HEAT OF FUSION OF ICE

The heat of fusion of ice, that is, the number of calories of heat required to change a gram of ice at 0° C. into water at 0° C., or the number given up when a gram of water changes to ice, may be determined experimentally as follows:

Weigh the inner vessel of a calorimeter of about 300 cc. capacity, first when empty and then after it has been filled about two-thirds full of water.*

Heat this water to a temperature of about 25° C. above that of the room; then support the inner vessel by its ring in the outer vessel of the calorimeter.

Prepare a lump of clear ice of about the size of a hen's egg and perform the following operations in quick succession:

While one student is drying the ice upon a towel, let another stir the water in the calorimeter thoroughly. If its temperature is less than 15° C. above that of the room, heat it up again until it is between 15° C. and 25° C. above. Again check the weight, for the loss by evaporation may not have been inappreciable. Stir vigorously; then quickly take a careful reading of the temperature, keeping the thermometer bulb all the time immersed, and not more than a second or two after the reading let the first student drop the dry ice into the water, being very careful not to spill a drop. The splash may often be avoided by letting the ice slide along the thermometer into the water.

Stir continuously while the ice is melting and read the temperature of the water just after the ice has all disappeared. This temperature should be from 2° C. to 10° C. below the temperature of the room. If it should happen to be above the room temperature, try again with a slightly larger piece of ice. The limits here given are chosen so as to make it legitimate to assume that the heat exchanges which take place between the calorimeter and the room are, on the whole, negligible.

Again weigh the inner vessel of the calorimeter, with its contained water, and take the difference between this weighing and the last as the weight of the ice.

Let x represent the heat of fusion of ice and w the weight in grams of the ice melted. Then the number of calories expended in melting the ice is wx. After the ice is melted it becomes w grams of water at 0° C. This water is then raised to the final temperature t of the mixture. The number of calories required for this operation is wt. All of this heat has come from the cooling of the water and the calorimeter. If the weight of the water cooled is W and its initial temperature t_1, while the water equivalent of the calorimeter is e, (.095 × weight of calorimeter), then the total number of calories given up by the water and calorimeter is $(W+e)(t_1-t)$. Hence, by equating "heat lost" and "heat gained," we have the equation $(W+e)(t_1-t)=wx+wt$, from which compute x.

Questions. *a.* What is meant by "latent heat of ice," the quantity which you found above?

b. Explain why ice rather than ice water is used to cool lemonade.

c. Explain what each part of your numerical equation represents.†

* If you use the small cylinders of Exp. 3 for the calorimeters, take just half of the amounts of ice and water indicated.

† A further experiment on latent heat, which may be introduced for the benefit of those who have time and inclination for extra work, is the following:

To find the heat of condensation of steam. Pass dry steam into, say, 250 g. of cold water, the temperature of which is 10° C. below that of the room, until the temperature is 10° above that of the room. Weigh again to find the weight w of the steam condensed.

Let x represent the heat of condensation of steam, that is, the number of calories of heat given up by a gram of steam in changing from steam to water at the same temperature. Then the number of calories of heat produced by the condensation of the steam is wx. The water formed by the condensation of the steam in cooling to the final temperature t of the mixture will give up $w(100-t)$ calories. If the weight of the water heated is W and its initial temperature t_1, while the water equivalent of the calorimeter is e, then the heat exchanges are given by the equation

$$wx + w(100-t) = (W+e)(t-t_1).$$

EXPERIMENT 22 (*Continued*)

RECORD OF EXPERIMENT

Weight of calorimeter = ...

Weight of calorimeter + water = ...

∴ weight of water = ...

Temperature of room = ...

Initial temperature of water = ...

Final temperature of water = ...

∴ fall in temperature of water = ...

Weight of calorimeter + water + ice = ...

∴ weight of ice = ...

Equation ....

∴ heat of fusion of ice, x, = ... cal.

Accepted value is 80.

∴ per cent of error = ...

EXPERIMENT 23

THE BOILING POINT OF ALCOHOL

The boiling point of a liquid is defined as the temperature at which the pressure of its saturated vapor becomes equal to the atmospheric pressure. There are, therefore, two ways in which the boiling point of alcohol may be obtained, and these two ways should give identical results. The first is to confine the liquid and its vapor alone in a closed vessel, and then to measure the pressure exerted by the vapor at different temperatures. That temperature at which the pressure becomes equal to atmospheric pressure will then be the boiling temperature. The second and more direct way consists in simply boiling the liquid in an open vessel and observing the temperature indicated by a thermometer held in the vapor rising from the liquid.

I. Temperature at which pressure of saturated vapor becomes equal to atmospheric pressure. A glass tube *A* (Fig. 41) is closed at one end, and is then bent into the U-shape and partially filled with mercury. Some alcohol is then poured in, which by careful tilting is worked around into the closed arm, while the air is altogether worked out of this arm. With this arrangement proceed as follows:

FIG. 41

Immerse the tube and a thermometer together in a vessel of water, and, keeping the short arm completely immersed, heat slowly, with constant stirring. As the temperature increases a point is reached at which alcohol vapor begins to form in the closed tube. Still further increase in temperature causes the mercury to sink farther and farther in the closed end. When the levels of the mercury in the two arms are the same, it is clear that the pressure of the alcohol vapor is just equal to the atmospheric pressure. Raise the temperature of the water gradually and stir thoroughly until this condition is reached; then read and record the temperature.

Continue heating until the level in the short arm is 5 cm. lower than that in the long one. Then again read the thermometer and compute how much the boiling point of alcohol increases per centimeter increase in the barometric pressure.

II. Temperature of vapor rising from boiling liquid. Place a little alcohol in a large test tube; put a few tacks in the bottom of the tube in order to insure smooth boiling; then immerse the lower end of the tube in a vessel of water and heat the water until the alcohol boils vigorously. Hold the bulb of a thermometer in the tube a little distance above the surface of the boiling liquid. As soon as the thermometer reading becomes stationary, take the temperature and compare with that obtained in I.

Questions. ***a.*** If the test tube of alcohol were placed under the receiver of an air pump, how would its boiling point change as the air was exhausted from the receiver?

b. If the boiling point of alcohol was determined in a deep mine, would it be higher or lower than you found it to be in I, (*b*) or II, (*a*). (See data record.)

RECORD OF EXPERIMENT

I. (*a*) Barometer reading = ... cm.

(*b*) Temperature at which alcohol vapor exerts a pressure equal to the atmospheric pressure = ... °C.

(*c*) Temperature at which alcohol vapor exerts a pressure equal to the atmospheric pressure + 5 cm. of mercury = ... °C.

(*d*) Rise in boiling point of alcohol per centimeter increase in pressure = ... °C.

(*e*) Boiling point of alcohol at 76 cm. pressure = ... °C.

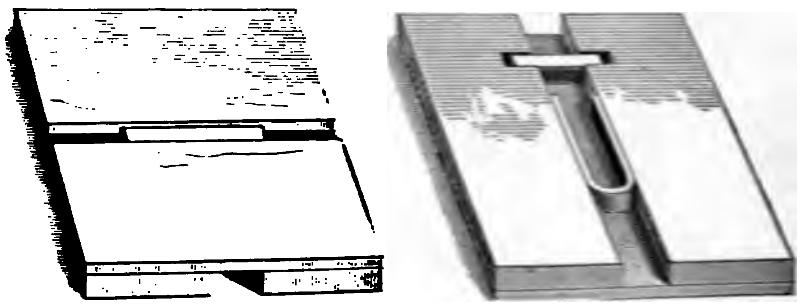
II. (*a*) Temperature of vapor rising from boiling alcohol = ... °C.

Difference between results of I, (*b*) and II, (*a*) = ... °C.

EXPERIMENT 25

MAGNETIC FIELDS *

I. The magnetic field about a bar magnet. (*a*) Lay a bar magnet in the groove of the board own in (Fig. 43, 1). Pin a sheet of blue-print paper over the magnet; from a sifter containing iron ings sift the filings evenly, but t too thickly, over the paper m a height of a foot or two. the paper gently with a pencil. filings will be found to have anged themselves in lines rung in symmetrical curves from pole around to the other.



1 2

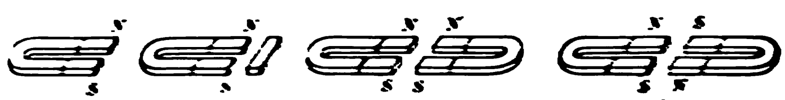
Fig. 43

(*b*) Hold a short compass dle in a number of positions r the board, and observe ether or not there is any connection between the direction of the curved lines and the direction en by the needle. These lines simply indicate the direction of the magnetic force. They are called *gnetic lines of force.* With a lead pencil indicate on the paper the *N* and *S* poles of the magnet.

(*c*) Carefully place the board in strong sunlight without jarring the filings, and wait until the covered parts of the paper have turned pale blue. Return the filings to the box and put the blue-nt paper to soak in water for about five minutes. Place the paper flat against a pane of glass to , and when it is dry fasten it in your notebook.

If blue-print paper is not provided, or if the sun is not bright enough to make satisfactory prints, ply draw in your notebook a copy of the curves shown by the filings. In these drawings, as on blue prints, indicate the *N* and *S* poles of the magnets and furnish the lines with arrows pointing the direction in which an *N* pole tends to move. (An *N* pole is one which, when the magnet is ely suspended, points toward north.)

II. The magnetic field about certain combinations of horseshoe magnets. Using the reverse side of



1 2 3 4

Fig. 44

board used in I and the horseshoe magnets of the improvised D'Arsonval galvanometer of Exp. 30, e blue prints or drawings of each of the illustrations in Fig. 44. Be sure to mark the location of *N* and *S* poles on each blue print or drawing. In 2, place the bar of soft iron about 1 in. from the of the magnet. In 3 and 4, place the ends of the magnets about 2 or 3 in. apart.

Questions. ***a.*** Does each iron filing become a magnet? How do you know?

b. Why do the filings point along the lines of force?

c. What is a line of force?

d. What is the nature of the lines of force between two attracting poles? between two repelling poles?

e. What property of iron does Fig. 44, 2, show?

* To make boards for this experiment make upper pieces of Fig. 43, 1, of same thickness as bar magnets and separate n by the width of the magnet. For the lower pieces of Fig. 43, 1 (upper of Fig. 43, 2), use pieces of same thickness as eshoe magnets and separate them by the width of the horseshoe magnet. A notch cut into these pieces receives the soft of Fig. 44, 2.

EXPERIMENT 26

MOLECULAR NATURE OF MAGNETISM

I. Making a permanent magnet. Mark one end of a knitting needle with a file for the sake of identification.

(*a*) Stroke it once from end to end with the *N* pole of a horseshoe or bar magnet. Place the needle on the table in the east-and-west line which passes through the middle of a compass needle resting upon the table, and slide the knitting needle up toward the compass until it produces in it a deflection of 10°; then mark the positions of the two ends of the knitting needle on the table. Does the near end of the knitting needle repel or attract the north-seeking end of the compass needle? Is it an *N* or an *S* pole? (If in doubt, suspend the needle in the middle by a thread and a wire stirrup and see which end points north.)

(*b*) Reverse the knitting needle so that the second end occupies exactly the position originally occupied by the first. Compare the strengths and signs of the two poles.

(*c*) Stroke the needle once more with the magnet precisely as at first, and again bring it to precisely the same position. Is the deflection increased? How much?

(*d*) Continue to stroke the magnet in the same way until it is saturated, that is, until further stroking produces no more change in the effect upon the compass.

II. Effect of jars on a saturated magnet. (*a*) Drop the needle on the floor and again test its strength exactly as before. Record the change.

(*b*) Strike the needle a number of sharp blows against the table and test again.

(*c*) If magnetization consists in a particular arrangement of the molecules of the needle, what effect would you expect violent jars like the above to have upon it?

III. Effect of breaking a magnetized needle. (*a*) Magnetize a long darning needle and note which end is *N* and which *S*. Then dip the whole needle into a box of iron filings and note whether or not it possesses any appreciable magnetism in the middle.

(*b*) Break it in two and test the two freshly broken ends first by means of the compass and then by means of the iron filings. Test also the old ends.

(*c*) Break one of the halves again if possible and repeat as above.

(*d*) Summarize the results of these experiments and explain the observed effects on the assumption that a magnet consists of rows of molecular magnets arranged end to end.

IV. Effects of heating a magnet. (*a*) Note how much deflection is produced when one of the small magnets, say, an inch long, obtained by breaking the darning needle, is placed at a given distance from the compass; then make a stirrup out of copper wire, place the needle in it, heat it to redness in the Bunsen flame, and again test it by means of the compass. Record the effect.

(*b*) Heat again to redness, and then transfer it quickly to a position between the poles of a horseshoe magnet. Let it remain there until cool and test again with the compass.

(*c*) Explain both of the effects on the assumption that magnetization consists in a particular arrangement of the molecular magnets. (Remember that the molecules of the needle are set into violent agitation when the needle is heated to redness.)

V. Making a magnet by induction. (*a*) Hold a short piece of unmagnetized knitting needle or a small steel nail parallel to the line joining the poles of a horseshoe magnet and tap it vigorously with some heavy object without allowing it to touch the magnet. Remove it and test its poles with the compass needle.

(*b*) Turn it end for end, replace it between the poles of the horseshoe magnet, and tap again. Record the change which you observe in its poles.

(*c*) Remove the steel rod from a tripod or take one of the small steel rods used for bending in Exp. 13. Hold it nearly vertical in a north-and-south plane, the upper end being tilted 20° or 30° toward the south. Strike the upper end three or four sharp blows with a hammer and then test the two ends of the rod for magnetism. Note which end is an *N* pole.

(*d*) Repeat with the ends of the rod reversed. Which end is now an *N* pole? Explain on the assumption that the molecules are permanent magnets and that magnetization consists in an alignment of these molecules.

From all of the above experiments, what picture do you make to yourself regarding the operations which go on within a bar of iron when it is magnetized? Draw a diagram to represent the probable arrangement of the molecular magnets in a magnetized bar, and another to represent some possible arrangement in an unmagnetized bar.

EXPERIMENT 27

STATIC ELECTRICAL EFFECTS

To make an electroscope, bend a piece of No. 18 copper wire into the form shown in Fig. 45, thrust it through a rubber stopper,* hang a piece of aluminum foil about 2 in. long over the horizontal part of the wire, and insert in a glass flask as shown.†

Fig. 45

I. Conductors and nonconductors. (*a*) Attach one of the steel balls of Exp. 3 to a silk thread by means of sealing wax, or simply stick a penny to the end of a glass rod with the aid of sealing wax. Such an arrangement is called a *proof plane*. Charge this proof plane by letting it rub along a stick of sealing wax which has been electrified by being rubbed with flannel; then touch it to the wire of the electroscope. What does the instant divergence of the leaves show regarding the ease with which a charge of electricity passes through this metal wire? What does the fact that the leaves stand apart show regarding the nature of the force which the two parts of the same charge going to the two leaves exert upon each other?

(*b*) Touch the wire of the electroscope for an instant with a piece of sealing wax which has not been electrified. Touch it with a wooden ruler. Touch it with your finger. Which of the three conducts off the charge most readily?

(*c*) Charge the proof plane, again touch it with the finger, and then try to charge the electroscope with it. Explain why the rubbed sealing wax holds its charge when it is held in the hand, while the proof plane loses its charge as soon as it is touched with the finger.

II. Positive and negative electricity. (*a*) Charge the electroscope as above, then bring the charged sealing wax toward it. Record the effect produced on the divergence of the leaves. Explain this effect in view of the fact that the charge on the wire of the electroscope is a part of the charge which was originally on the sealing wax (see I, (*a*)).

(*b*) Rub a glass rod with silk, then bring it slowly toward the charged electroscope. Record the first effect observed. (If you bring the rod too close, the effect will be reversed.) In order to account for this effect, what sort of a force must we now assume the charge on the glass rod to exert upon the charge on the electroscope?

A charge of electricity which acts as does the charge on a glass rod which has been rubbed with silk is arbitrarily called a *positive* (+) charge. A charge which acts like the charge on the sealing wax when it has been rubbed with flannel is called a *negative* (−) charge.

(*c*) Discharge the electroscope, then charge it with the aid of the proof plane and glass rod, precisely as you first charged it with the aid of the proof plane and sealing wax. Note and record the behavior of the leaves when you now bring first the glass rod and then the charged sealing wax toward the electroscope. In view of all of these observations, state how, in general, *like* and *unlike* charges of electricity act upon one another.

(*d*) Charge the electroscope either positively or negatively; then rub a piece of paper on the coat sleeve and determine by bringing the paper near the electroscope whether it has received a + or a − charge. Flick your handkerchief across the suspended steel ball and see whether it has received a + or a − charge.

* If the rubber stopper has not a hole through it already, you can easily make one with a hot knitting needle. If it already has a hole which is too large, cover the wire with sulphur or with sealing wax. This will not only make it fit but will also improve the insulation.

† An electroscope so made will hold its charge for hours, even in summer. To cut the foil blow it out flat on a sheet of paper, lay another sheet on top of it, leaving one edge uncovered, and then cut off a strip with a sharp knife or razor. A saw stroke will work best.

up to within about 1 or 2 mm. of A. What effect do you find that this has on the potential of A? (Consider potential to be measured by the divergence of the leaves of the electroscope.)

(*b*) Electrify the sealing wax again, as nearly as possible in the way you did at first, and give A another stroke. Repeat until the original divergence is reëstablished. From the number of these strokes estimate roughly how many times the *electrical capacity* of A has been increased by the presence of B; that is, how many times the original amount of electricity is now required to bring it to the same potential which it had at first. In view of the fact that the – charge on A repelled negative electricity to the earth through your finger and thus induced a + charge on B, can you see why, when B is near by, it takes a larger charge on A to produce a given divergence than when B is remote?

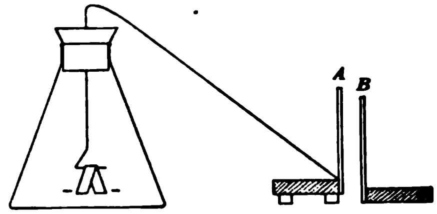


FIG. 47

(*c*) Slip a 5 × 5 in. glass plate between A and B and watch the electroscope. Does this increase or decrease the potential of A? Hence does it increase or decrease the capacity of the *condenser?*

Push the plates together until each is in contact with the glass plate. Remove the glass without changing the distance between the plates, and charge A to a given divergence. Insert the glass and find how many more approximately equal charges may now be put on A before bringing the leaves to about the same divergence. The ratio of the charge on A when the glass was in to the charge when the glass was out is called the *specific inductive capacity* of glass.

VIII. The electrophorus. Charge the hard rubber plate B of Fig. 48 by rubbing it with fur or flannel. Place metal plate A on B. Touch A with your finger. When touched what kind of a charge will be repelled out of A to earth by the legative on B? What kind will be left on A? By means of the insulating handle ift A and bring it toward a positively charged electroscope. What happens? his shows A to be positively or negatively charged? Try lighting a Bunsen urner by holding it in the hand and allowing the spark to pass off the edge of A the top of burner while the gas is partly turned on. Does the charge on A come from B? Give ason for your answer. Why can you charge A an indefinite number of times in the above manner? There does the energy represented in the spark which lights the gas come from?

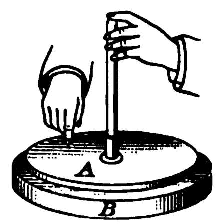


FIG. 48

EXPERIMENT 28

THE VOLTAIC CELL

I. Action of dilute sulphuric acid on copper and zinc strips. (*a*) *Open circuit.* Fill a tumbler two-thirds full of water and add about one sixtieth as much sulphuric acid. Introduce into the acid a strip of zinc about a centimeter wide and observe and record what effect, if any, is produced by the acid. (The bubbles are hydrogen.)

Repeat the experiment with a similar strip of copper.

Next place both the zinc and the copper in the acid at the same time, but take care that they do not touch each other at any point. Observe and record the action at each plate.

(*b*) *Closed circuit.* Press the tops of the strips firmly together and notice what change, if any, takes place at the surface of each metal. Record the results.

II. Effect of amalgamation. Dip the zinc plate into a dish containing a little mercury and rub the mercury over the wet portion of the zinc until it is covered with a smooth, even coat of mercury. Dip the amalgamated zinc into the sulphuric acid solution again, and repeat the observations of I, recording what differences, if any, are observed in the action.

III. Effects observable about the wire connecting the strips. (*a*) For convenience in handling, place strips of copper and of amalgamated zinc in clamps such as those shown in Fig. 49 and connect these clamps by means of, say, No. 24 copper wire to the binding posts of the 25-turn coil of No. 22 wire on the galvanoscope, after placing the latter with the plane of its coils north and south. Dip the metals in the acid and observe the effect on the needle.

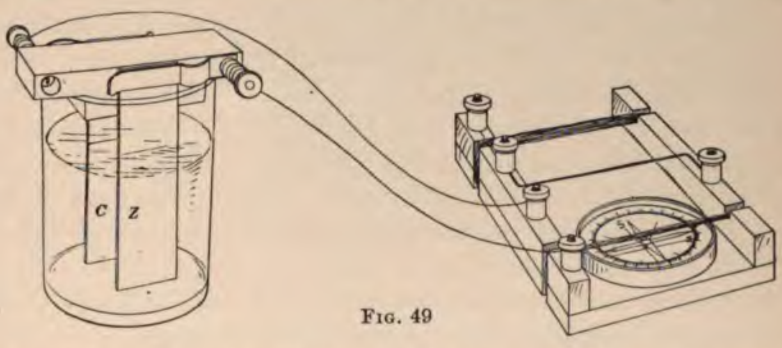


FIG. 49

(*b*) Disconnect the wires from the galvanoscope and touch them to the tongue. What evidence do you obtain of some action going on when the plates are in the acid, but which disappears as soon as they are lifted from it?

IV. Polarization. Take a fresh and dry copper plate or else dry the old one by heating it in a Bunsen flame until it is much too hot to hold and then letting it cool. Insert the zinc and copper in the clamps and connect as before to the 25-turn coil of the galvanoscope, but this time insert into the circuit about a meter of No. 36 German-silver wire.* (No. 30 will do, but No. 36 is better.) Turn the compass until the needle points to 0°; then immerse the plates in the acid, and, as soon as the needle stops swinging violently, read the deflection. (If this deflection is more than 40° or 50°, slide the compass along in the frame away from the 25-turn coil, until the deflection is reduced to 50° or less.) Watch the needle for a minute and record what you observe. In II you found that if the zinc is well amalgamated, hydrogen appears only at the copper plate. Short-circuit the cell for half a minute by holding a short strip of copper in contact with both the copper and zinc plates. This simply enables the hydrogen to be generated in greater abundance. It brings the deflection nearly to 0 because most of the current now goes through the copper strip. Remove the copper strip. Does the deflection return quite to its old value? From these experiments what effect do you conclude that

* For the sake of avoiding loose German-silver wire, it is best to insert the meter of No. 36 wire between the binding posts *1* and *a* of Fig. 63, and then to connect the zinc plate of the cell to *a*, the copper plate to one terminal of the galvanoscope, and the other terminal of the galvanoscope to 1.

the accumulation of hydrogen upon the copper plate has upon the strength of the current which the cell can furnish? This is technically called the *polarization* of the cell, and a cell in which this effect occurs is called a *polarizing* cell.

V. A nonpolarizing cell. Replace the simple cell by a Daniell cell, or construct what is essentially a Daniell cell as follows: First dry the copper plate in the Bunsen flame, then replace it in its clamp. Fill the tumbler half full of a saturated solution of copper sulphate and pour zinc sulphate into a small porous cup, which is then to be placed inside the tumbler. Now immerse the plates in the liquids, the zinc going into the zinc sulphate in the porous cup and the copper into the copper sulphate. (The porous cup is simply to keep the two liquids separated. The electric current can pass through it with ease.) Watch the needle and record its behavior. Short-circuit the cell and see if thereafter the deflection returns to its old value. Is, then, a Daniell cell a polarizing or a nonpolarizing cell? Does the fact that the element which is deposited on the copper plate when it is immersed in copper sulphate is *copper itself* suggest to you any reason why in this case the current is not changed, as was found to be the case when the deposit was hydrogen? In which case is the character of the surface of the plate *changed* by the deposit?

VI. A polarizing commercial cell. Replace the Daniell by a Leclanché cell, if one is available (a dry-cell will answer nearly as well). This consists of a zinc rod in sal ammoniac and a carbon plate inside a porous cup which is full of manganese dioxide. See first whether the current which this cell sends through the three feet of No. 36 German-silver wire weakens at all in two minutes. (If the deflection is more than 45°, push the compass farther away or change to the one-turn coil.) Then short-circuit the cell for half a minute and see if thereafter the deflection returns to the old value. Is, then, this cell polarizing or nonpolarizing? Watch the needle for a minute after the cell has been short-circuited. Does the current gradually recover part of its former strength? Break the circuit entirely and let the cell stand for a few minutes; then read the deflection.

Try the same experiment with a simple cell. Record the difference in the behavior of the two cells. This difference is due to the fact that in the simple cell there is nothing to remove the film of hydrogen from the surface of the plate upon which it is deposited. In the Leclanché cell, on the other hand, the manganese dioxide slowly unites with the hydrogen and therefore removes it from the carbon plate. This is indeed the object of its use. A Leclanché cell is, then, one which recovers on open circuit.

EXPERIMENT 28 A

THE VOLTAIC CELL

I. Action of dilute sulphuric acid on copper and zinc strips. (*a*) *Open circuit.* Fill a tumbler two-irds full of water and add about one sixtieth as much sulphuric acid. Introduce a strip of zinc out a centimeter wide into the acid and observe and record what effect, if any, is produced by the id. (The bubbles are hydrogen.)

Repeat the experiment with a similar strip of copper.

Next place both the zinc and copper in the acid at the same time, but take care that they do not uch each other at any point. Observe and record the action at each plate.

(*b*) *Closed circuit.* Press the tops of the strips firmly together and notice what change, if any, kes place at the surface of each metal. Record results.

II. Effect of amalgamation. Dip the zinc plate into a dish containing a little mercury and rub the ercury over the wet portion of the zinc until it is covered with a smooth, even coat of mercury. Dip e amalgamated zinc into the sulphuric acid solution again, and repeat the observations of I, recording hat differences, if any, are observed in the action.

III. Effects observable about the wire connecting e strips. (*a*) For convenience in handling, place rips of copper and of amalgamated zinc in clamps ch as those shown in Fig. 50.

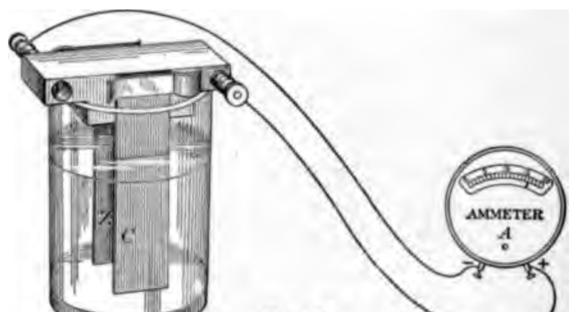


FIG. 50

Take about 5 ft. of No. 24 copper wire, loop the iddle portion of it 3 or 4 times around a compass such a way that the plane of the coil is north and uth, and then connect the two ends of the coil to e clamps shown in Fig. 50. Dip the metals in the id and observe the effect on the needle.

(*b*) Attach two wires to the cell and touch the ends of them to the tongue. What evidence do u obtain of some action going on when the plates are in the acid, but which disappears as soon as ey are lifted from it?

IV. Polarization. (*a*) Take a fresh and dry copper plate, or else dry the old one by heating it in Bunsen flame until it is much too hot to hold and then letting it cool. Insert the zinc and copper the clamps and connect them, as in Fig. 50, to a low reading ammeter, by means of two pieces of . 30 copper wire each about 1 m. long. Now watch the ammeter reading closely and at the same e immerse the plates in the acid, being sure to read the highest amperage which the cell will nish when the plates are first immersed. Record this reading.

(*b*) Watch the ammeter for two minutes and record what you observe, together with the ammeter ding at the end of the two minutes.

(*c*) Short-circuit the cell for one minute by holding a short strip of copper in contact with both copper and the zinc plate. This enables the cell to furnish a larger current, but brings the meter reading nearly to zero because most of the current now goes through the copper strip. serve the cell while it is short-circuited and note that as this larger current is drawn from the cell accompanied by a more rapid evolution of hydrogen in the cell. Remove the copper strip and record the ammeter reading. Does the cell now furnish as large a current as it did just before as short-circuited? (See ammeter reading in (*b*).)

From these experiments what effect do you conclude that the accumulation of hydrogen upon the er plate has upon the strength of the current which the cell can furnish? This is technically d the *polarization* of the cell, and a cell in which this effect occurs is called a *polarizing* cell.

V. A nonpolarizing cell. (*a*) Replace the simple cell by a Daniell cell or construct what is essentially a Daniell cell, as follows: First dry the copper plate in the Bunsen flame, then replace it in its clamp. Fill the tumbler half full of a saturated solution of *copper sulphate* and pour *zinc sulphate* into a small porous cup, which is then to be placed inside the tumbler. Now immerse the plates in the liquids, the zinc going into the zinc sulphate in the porous cup and the copper into the copper sulphate. (The porous cup is simply to keep the two liquids separated. The electric current can pass through it with ease.) As in IV, watch the ammeter reading for two minutes. Short-circuit the cell for one minute and see if thereafter the ammeter reading returns to its old value.

Is, then, a Daniell cell a polarizing or a nonpolarizing cell? Does the fact that the element which is deposited on the copper plate when it is immersed in copper sulphate is *copper itself* suggest to you any reason why in this case the current is not changed, as was found to be the case when the deposit was hydrogen? In which case is the character of the surface of the plate *changed* by the deposit?

VI. A polarizing commercial cell. Replace the Daniell cell by either a Leclanché or a dry cell. Record (*a*) the current when the cell is first connected to the ammeter; (*b*) the current at the end of two minutes; (*c*) the current after the cell has been short-circuited for half a minute.

Is this cell polarizing or nonpolarizing?

Watch the ammeter for the minute following the removal of the short circuit. Does the current gradually recover part of its former strength? Break the circuit entirely and let the cell stand for three or four minutes; then record the ammeter reading.

Try the simple cell used in IV and see if it will recover any of its strength after being short-circuited. What is the difference in the behavior of these two polarizing cells? This difference is due to the fact that in the simple cell there is nothing to remove the film of hydrogen from the surface of the plate upon which it is deposited. In either the Leclanché or the dry cell, on the other hand, the manganese dioxide slowly unites with and therefore removes the hydrogen from the carbon plate. This is indeed the object of its use. A Leclanché or a dry cell is, then, one which recovers on open circuit.

EXPERIMENT 29

MAGNETIC EFFECT OF A CURRENT

I. The right-hand rule, or Ampère's rule. Since a wire through which a current is flowing has just been found to deflect a magnetic needle held near it, the wire must be surrounded by magnetic lines of force. *The direction in which the N pole of the magnetic needle tends to move gives, by definition, the direction of these magnetic lines.*

The direction in which the positive electricity flows through the circuit of a zinc-copper cell is from zinc to copper inside the liquid and from copper to zinc in the connecting wire; that is, it flows in the direction in which the hydrogen was found to move in the last experiment. We know this because a very delicate electroscope will show that on open circuit the copper plate acquires a small + charge of static electricity and the zinc a small − charge. For this reason the copper or carbon plate of a voltaic cell is always called the *plus* (+) plate and the zinc the *minus* (−) plate. *The direction of an electric current is defined as the direction in which the positive electricity moves.*

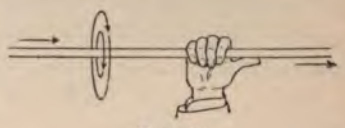


FIG. 51

By the series of experiments given below, test the following rule: *If the conductor is grasped by the right hand so that the thumb points in the direction in which the current flows, then the magnetic lines of force pass in concentric circles around the wire in the direction in which the fingers of the hand encircle it* (Fig. 51).

(*a*) Connect either a simple cell or a dry cell in the manner shown in Fig. 52, so that the current will flow from the copper (or carbon) through the commutator *C*, then over the needle from south to north, and back through the commutator to the zinc. All of the connecting wires should be copper (for example, No. 24), and that to the right of the commutator should be 10 or 12 ft. long. Insert the top of the commutator and record the direction in which the north pole of the needle turns.

(*b*) Turn the top of the commutator through 90°, so that the mercury cup *a* is connected to *e* and *b* to *d*, instead of *a* to *b* and *e* to *d*. This reverses the current in the wire so that it goes over the needle from north to south. Record the effect on the needle and compare with Ampère's rule.

(*c*) Place the compass above the wire without changing the direction of the current, and compare with the rule the effect produced on the needle. Reverse the direction of the current by means of the commutator and again compare.

(*d*) Hold the wire so that the current flows vertically *downward* just in front of the *N* pole of the compass; then cause the current to flow upward past the same pole, and test the rule in each case.

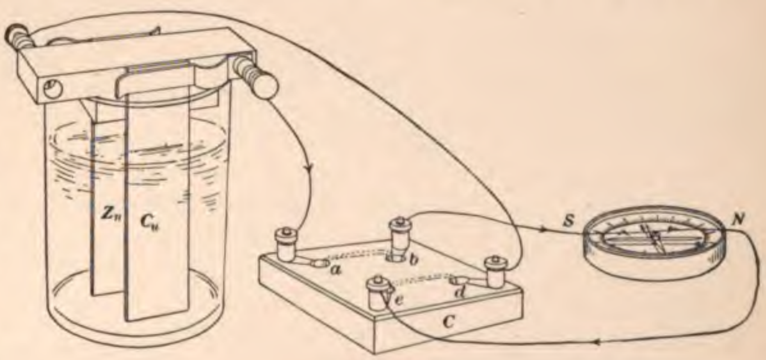


FIG. 52

(*e*) Hold the wire so that the current flows from west to east over the middle of the needle.

Does the experiment show that the lines of magnetic force lie in planes at right angles to the direction of the wire? How?

II. To find the direction of an unknown current. Let the instructor bring a current the direction of which is unknown into the laboratory by a wire connected with a cell in a closet or in an adjoining room. Hold a compass needle near the wire and determine the direction in which the current is flowing in the wire. Record your result and then test the correctness of it by following the wire to the cell.

III. The effect of loops. (*a*) As in I, pass a current from a cell over the compass from north, keeping the wire as close to the face of the compass as possible. Note the amount of d If this is more than 4°, introduce enough German-silver wire to make the deflection just 4 cause the wire to return beneath the needle, so that a loop is formed, in the upper part of which the current flows past the needle from south to north, and in the lower part from north to south. Again note the amount of deflection. How do you account for this last deflection?

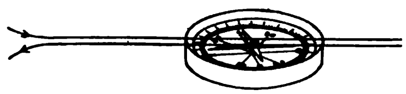


FIG. 53

(*b*) Loop the wire two and then three times around the compass in such a way that the the coil is north and south and record the deflection in each case. What change is produc deflection by each new turn? Explain.

(*c*) Try the effect of placing both sides of the loop above the needle, as in Fig. 53. Ex observed effect.

RECORD OF EXPERIMENT

	DIRECTION OF CURRENT	POSITION OF COMPASS	*N* POLE OF NEEDLE IS DEFLECTED TOWARD
I, (*a*)	South to north	Under wire	
(*b*)	North to south	Under wire	
(*c*)	North to south	Above wire	
(*d*)	Vertically down	South of wire	
	Vertically up	South of wire	
II			
III, (*a*)	South to north	Under wire	Deflection = ...°
	Around 1 loop	Between wires	Deflection = ...°
(*b*)	Around 2 loops	Between wires	Deflection = ...°
	Around 3 loops	Between wires	Deflection = ...°
(*c*)	As in Fig. 53	See Fig. 53	Deflection = ...°

EXPERIMENT 30

MAGNETIC PROPERTIES OF COILS CARRYING CURRENTS, AND THEIR APPLICATION TO THE ELECTRIC BELL AND THE D'ARSONVAL GALVANOMETER

I. **Magnetic effect of a helix.** (*a*) Having the circuit arranged as in Fig. 52, the current being furnished either by a simple cell or by a dry cell, form a close helix (see Fig. 54) by wrapping the conducting wire forty or fifty times around a lead pencil. Then with the aid of the compass see whether or not the helix is a magnet; that is, whether one end of it attracts the north pole while the other repels it.

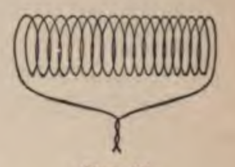


FIG. 54

(*b*) By means of the commutator reverse the direction of the current through the helix and record what effect is thus produced upon the poles.

(*c*) Test the following rule for determining the poles of a helix: *If the helix is grasped in the right hand so that the fingers are pointing in the direction in which the current is flowing in the coils* (see Fig. 55), *the thumb will point in the direction of the magnetic lines of force; that is, the thumb will point towards the north pole of the helix.* Show how this rule follows from Ampère's rule.

II. **The principle of the electromagnet.** (*a*) Thrust an unmagnetized soft-iron rod (for example, a wire nail) into the helix and then test the nail and helix together in the same way in which the helix alone was tested in the preceding experiment. Are the poles stronger or weaker than before?

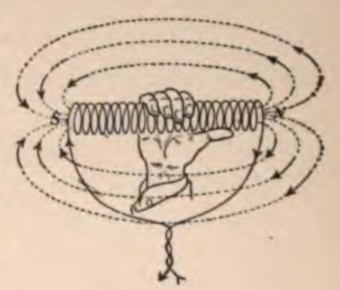


FIG. 55

(*b*) Reverse the current by means of the commutator and test and record the effect on the poles.

(*c*) Bend a piece of large iron wire into the shape of a letter U and mark one end with chalk. About the ends of both arms of the U wind a wire carrying a current, in such a way that the marked end of the U shall be an N magnetic pole and the other an S pole. Test by means of a compass.

III. **Use of the electromagnet in an electric bell.** (*a*) Connect an electric bell with a dry cell, and with an inexpensive compass test the condition of the electromagnet, first when the clapper is held against the bell, then when it is held away from it. Trace the current through the instrument and, with the aid of a diagram, explain in your notebook why the bell rings.

(*b*) Connect a bell, two push buttons, and a cell in such a way that pushing either button will ring the bell.

IV. **Principle of the D'Arsonval galvanometer.** (*a*) Hang a coil of about one hundred and seventy-five turns of No. 32 copper wire between the poles of a horseshoe magnet in the manner shown in Fig. 56, so that the plane of the coil is parallel to the line joining the poles. The two wires which run from the coil up to the cork support should be of No. 40 insulated copper, and one of them should be twisted about the other loosely, as in the figure. Pass a current from a cell, first through a commutator and then through the coil. Record the effect observed in the coil.

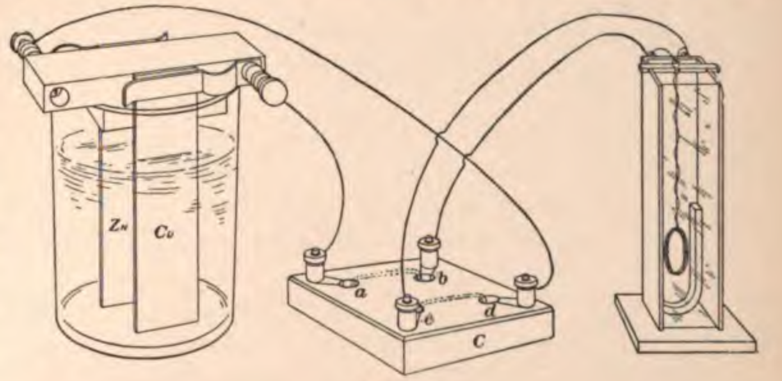


FIG. 56

(*b*) Reverse the direction of the current and observe the effect produced. Explain why the c turns as it does, remembering that it is nothing but a flat helix.

(*c*) By rotating the cork at the top, set the coil between the poles of the magnet in such a w that its plane is perpendicular to the line joining these poles. Turn on the current and note the eff

(*d*) Reverse the current and note again the effect. Explain in each case the effect observed.

Questions. ***a.*** As you look at the N pole of an electromagnet does the current encircle it in a clockw or counterclockwise direction ?

b. Devise an experiment by means of which you could make a permanent magnet without the use o magnet.

c. Name two or three instruments or machines which make use of the electromagnet.

d. In IV, (*d*), when the current through the coil was reversed, the coil made a half turn. If the coil w free to turn, as in a motor, would it be possible to get continuous rotation of the coil by reversing the c rent through the coil at the proper times ?

EXPERIMENT 31

UPON WHAT DOES THE ELECTROMOTIVE FORCE (E.M.F.) OF A CELL DEPEND?

In the present experiment we shall compare the *electromotive forces*, or the *electric pressures*, which cells of different form are able to maintain, by comparing the currents which they can force through coils of comparatively high resistance: that is, through voltmeters.

I. Effect of size of plates and distance between them on the electromotive force of a cell. (*a*) Connect the zinc and the copper strip of a simple cell to a low-reading voltmeter as shown in Fig. 57. Lower the plates about 2 or 3 cm. into the sulphuric-acid solution and note the reading of the voltmeter.

(*b*) Lower the plates into the solution until the plate holder rests on the glass and again note the reading of the voltmeter.

(*c*) Remove the copper plate from its holder and press the wire, which was attached to the holder, against the copper strip. Now observe the voltmeter reading when the copper strip is held as far away from the zinc as is possible in the tumbler, and again when it is held very close to, but not touching, the zinc strip.

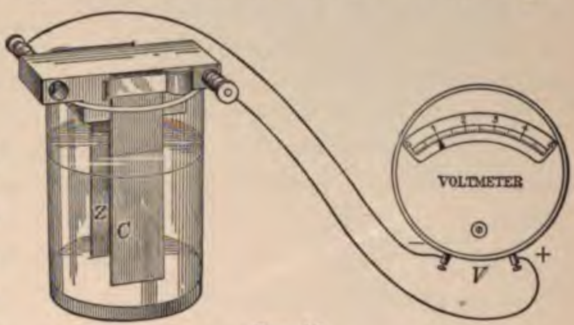


FIG. 57

What conclusions do you draw in regard to the effect of the distance between the plates and the area of immersion of the plates on the electromotive force of a cell?

II. Effect of different metal plates on the electromotive force of a cell. (*a*) Substitute a lead plate for the copper one and record the E.M.F. of this cell as read on the voltmeter. Record also which metal is + and which is −. (Remember that the metal connected to the + marked binding post of the voltmeter is +, and that the one connected to the − marked binding post is the − one.) Record the E.M.F. of the cell when the following plates are used: zinc-copper, zinc-lead, zinc-carbon, and zinc-aluminum.

(*b*) Replace the zinc by a lead plate and record the E.M.F. produced by lead-copper, lead-aluminum, and lead-carbon.

Do you see any connection between the results in (*a*) and (*b*) which enables you to predict all the results in (*b*) from those in (*a*)?

(*c*) If so, arrange these five substances in a list such that each substance will be positive with respect to any substance following it in the list, but negative with respect to any substance preceding it. Which pair gives the highest E.M.F.?

What conclusion do you draw in regard to the effect on the E.M.F of the kind of plates used?

III. Effect of different liquids (electrolytes) on the E.M.F. of a cell. (*a*) Record the E.M.F. produced when zinc and copper are immersed (1) in dilute sulphuric acid (H_2SO_4); (2) in a solution of common salt, that is, sodium chloride ($NaCl$); (3) in a solution of sodium carbonate (Na_2CO_3); (4) in common water (H_2O).

Rinse the plates thoroughly before placing them in a new liquid.

(*b*) Now record the E.M.F. and the sign of the plates when copper and iron are immersed (1) in dilute sulphuric acid; (2) in a weak solution of ammonium sulphide ($(NH_4)_2S$) — about 20 drops in a tumbler of water will do. What effect has the change in the liquid had upon the direction of the E.M.F.?

What conclusion do you draw in regard to the effect of the electrolyte on the direction and magnitude of the E.M.F. of a cell?

IV. Effect of series and of parallel connection on the E.M.F. of the combination. (*a*) Join two simple cells or dry cells *in series* (that is, the zinc, *Z*, of one to the copper or carbon, *C*, of the other (Fig. 58)), and record the E.M.F. of the combination when connected to the voltmeter.

Record also the E.M.F. of each cell alone. Compare the E.M.F. of the two cells when connected in series with that produced by a single cell.

(*b*) Connect the two similar cells *in parallel* (that is, zinc to zinc and copper to copper); connect to the voltmeter as in Fig. 59, and record the E.M.F. of the combination. How does the E.M.F. of the two cells in parallel compare with that of a single cell?

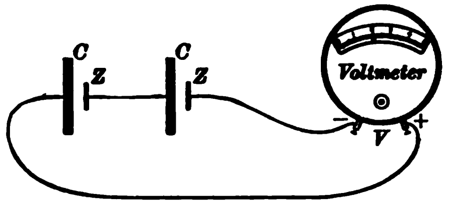


FIG. 58

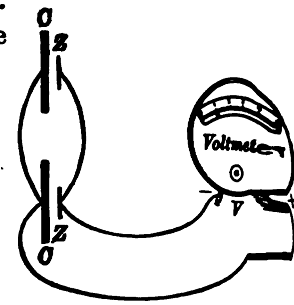


FIG. 59

What conclusions do you draw as to the effects of series and of parallel connections on E.M.F.?

V. Electromotive forces of various commercial cells. With the voltmeter measure the E.M.F. of several commercial cells such as the Daniell cell, dry cell, Leclanché cell, etc.

RECORD OF EXPERIMENT

I. (*a*) Metals immersed 2 or 3 cm., E.M.F. = ... volts.

(*b*) Metals completely lowered, E.M.F. = ... volts.

(*c*) Metals far apart, E.M.F. = ... volts.

Metals close together, E.M.F. = ... volts.

II. (*a*) Zinc –, copper +, E.M.F. = ... volts.

Zinc ...., lead ...., E.M.F. = ... volts.

Zinc ...., carbon ...., E.M.F. = ... volts.

Zinc ...., aluminum ...., E.M.F. = ... volts.

(*b*) Lead ...., copper ...., E.M.F. = ... volts.

Lead ...., aluminum ...., E.M.F. = ... volts.

Lead ...., carbon ...., E.M.F. = ... volts.

(*c*) Order of metals such that each is + with respect to any following it:

carbon, ..., ..., ..., zinc.

III. (*a*) Zinc-copper, in H_2SO_4, E.M.F. = ... volts; in NaCl, E.M.F. = ... volts;

in Na_2CO_3, E.M.F. = ... volts; in H_2O, E.M.F. = ... volts.

(*b*) Copper ...., iron ...., in H_2SO_4, E.M.F. = ... volts.

Copper ...., iron ...., in $(NH_4)_2S$, E.M.F. = ... volts.

IV. (*a*) E.M.F. of 2 cells in series = ... volts; of cell 1 = ... volts; of cell 2 = ... volts.

(*b*) E.M.F. of 2 cells in parallel = ... volts.

V. E.M.F. of Daniell cell = ... volts; of .... cell = ... volts;

of .... cell = ... volts; of .... cell = ... volts.

EXPERIMENT 31 A

UPON WHAT DOES THE ELECTROMOTIVE FORCE (E.M.F.) OF A CELL DEPEND?

In the present experiment we shall compare the *electromotive forces*, or the *electric pressures*, which cells of different form are able to maintain, by comparing the currents which they can force through a long piece of fine wire (a large resistance).

I. Effect of size of plates and distance between them on the electromotive force of a cell. To one of the terminals of the 100-turn coil of the galvanoscope connect a small coil *R* (Fig. 60) of German-silver wire the resistance of which is about 1000 ohms. Then complete the circuit of the simple cell through this high-resistance galvanometer in the manner shown, and read the deflection of the needle. If it is more than 20°, push the compass farther away from the coil. Lift the plates almost out of the liquid and read again. Disconnect the wires from the binding posts of the cell, remove the frame and plates from the tumbler, press the wires very firmly against much narrower zinc and copper strips than those used before, immerse these in the liquid, and read again. Place these strips as far apart in the tumbler as you can, and see if the deflection changes as you move them together. (In all cases in which accurate readings of deflections are to be taken it is desirable to tap the frame of the galvanometer lightly with a pencil so as to overcome any tendency which the needle may have to stick.)

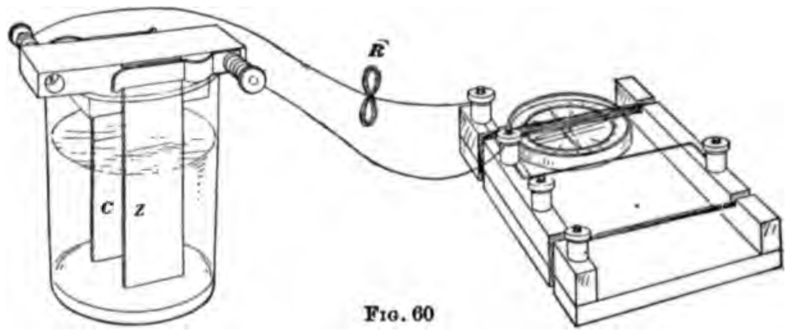


Fig. 60

What conclusion do you draw in regard to the effect of the distance between the plates and of the area of immersion of the plates on the electromotive force of a cell?

II. Effect of different metal plates on the electromotive force of a cell. (*a*) Without changing anything else in the circuit, insert in the clamp of the simple cell a lead plate in place of the copper plate of the above experiment. If the needle is deflected in the same direction as before, we may know that in the external circuit the current flows from the lead to the zinc, that is, that lead in sulphuric acid is + with respect to zinc; but if the needle turns in the opposite direction, then the zinc is + with respect to the lead. Record tests with zinc-lead, zinc-carbon, and zinc-aluminum electrodes.

(*b*) Replace the zinc plate by one of lead, and record tests on lead-copper, lead-aluminum, and lead-carbon electrodes.

(*c*) Do you see any connection between the results in (*a*) and (*b*) which enables you to predict all the results in (*b*) from those in (*a*)? If so, arrange these five substances in a list such that each substance will be positive with respect to any substance following it in the list, but negative with respect to any substance preceding it. Which pair give the highest E.M.F.? What conclusion do you draw in regard to the effect on the E.M.F. of the kind of plates used?

III. Effect of different liquids (electrolytes) on the E.M.F. (*a*) Measure the deflection, using the same galvanoscope, when zinc and copper are immersed (1) in dilute sulphuric acid (H_2SO_4); (2) in a solution of common salt (NaCl, that is, sodium chloride); (3) in a solution of sodium carbonate (Na_2CO_3); (4) in tap water (H_2O). Rinse the plates thoroughly before placing them in a new liquid.

EXPERIMENT 31 A (*Continued*)

(*b*) Now place copper and iron strips in the clamps of the cell, immerse in the sulphuric acid solution, and read; then immerse the same strips in a weak solution of ammonium sulphide ($(NH_4)_2S$) — about 20 drops in a tumbler of water will do. What effect has the change in the liquid had upon the direction of the current?

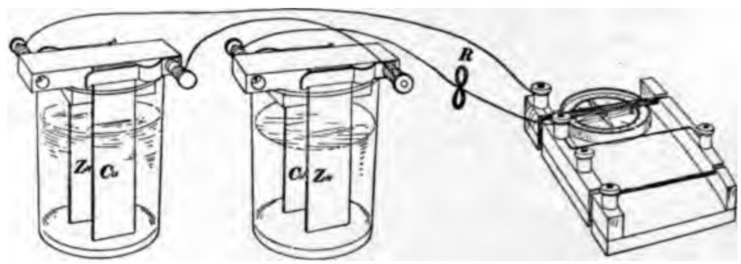


FIG. 61

What conclusion do you draw in regard to the effect of the electrolyte on the direction and magnitude of the E.M.F. of a cell?

IV. Effect of series and of parallel connection on the E.M.F. of the combination. (*a*) Connect the high-resistance circuit to the terminals of a single cell and read the deflection. If this is more than 8° or 10°, push the compass away from the coil until it is reduced to about this value. (The object of making the deflection small is to arrange the conditions so that the E.M.F. may be taken as proportional to the deflections.)

(*b*) Join two similar cells in series, that is, the zinc of one to the copper of the other (Fig. 61), and read the deflection when connected to the same circuit.

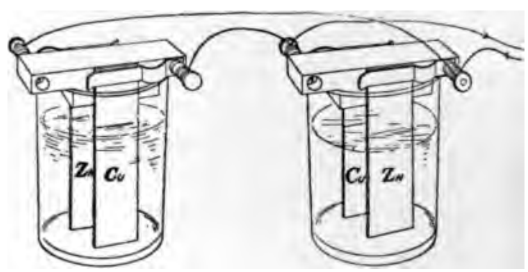


FIG. 62

(*c*) Connect the two similar cells in parallel, that is, zinc to zinc and copper to copper (Fig. 62), again read the deflection, and compare with that produced by a single cell.

What conclusions do you draw in regard to the effects of series and of parallel connections on E.M.F.?

V. Electromotive forces of various commercial cells. Having the galvanometer circuit arranged as in Fig. 56, reduce the deflection produced by a Daniell cell, improvised as in Exp. 28, V, to about 10° by moving the compass away from the coil; then find the deflections produced by a dry cell, a Leclanché cell, and any other cells which you may have, and calculate the E.M.F. of all the latter cells on the assumption that the E.M.F. of a Daniell cell is 1.08 volts. In this work, however, be very careful not to change the galvanoscope in any way during any of the operations.

RECORD OF EXPERIMENT

I. Deflection, plates immersed = ...°, plates partly immersed = ...°,
For narrow strips far apart = ...°, close together = ...°.

	METALS USED	ELECTROLYTE	DEFLECTION		METALS USED	ELECTROLYTE	DEFLECTION
II. (*a*)	Zinc — copper +	H_2SO_4		III. (*a*)	Zinc ... copper ...	H_2SO_4	
	Zinc ... lead ...	H_2SO_4			Zinc ... copper ...	NaCl	
	Zinc ... carbon ...	H_2SO_4			Zinc ... copper ...	Na_2CO_3	
	Zinc ... aluminum ...	H_2SO_4			Zinc ... copper ...	H_2O	
(*b*)	Lead ... copper ...	H_2SO_4		(*b*)	Copper ... iron ...	H_2SO_4	
	Lead ... aluminum ...	H_2SO_4			Copper ... iron ...	$(NH_4)_2S$	
	Lead ... carbon ...	H_2SO_4					

IV. (*a*) Deflection for a single cell = ...°, (*b*) for 2 cells in series = ...°, (*c*) for 2 cells in parallel = ...°.
V. Deflection for a Daniell cell = ..., for a Leclanché cell = ...°, for a .... cell = ...°.
E.M.F. of a Daniell cell = 1.08 volts, ∴ of a Leclanché cell = ... volts, ∴ of a .... cell = ... volts

EXPERIMENT 32

OW DOES THE RESISTANCE OF ELECTRICAL CONDUCTORS DEPEND UPON THE LENGTH, DIAMETER, MATERIAL, AND METHOD OF CONNECTION?

. **Length.** (*a*) Connect two dry cells or a storage battery in series with a key, K, an ammeter, and :m. of No. 30 German-silver wire (wire 1 of Fig. 63). Close the key and record the ammeter ng and the voltmeter reading ı the voltmeter is connected ıs 50 cm. of the wire.

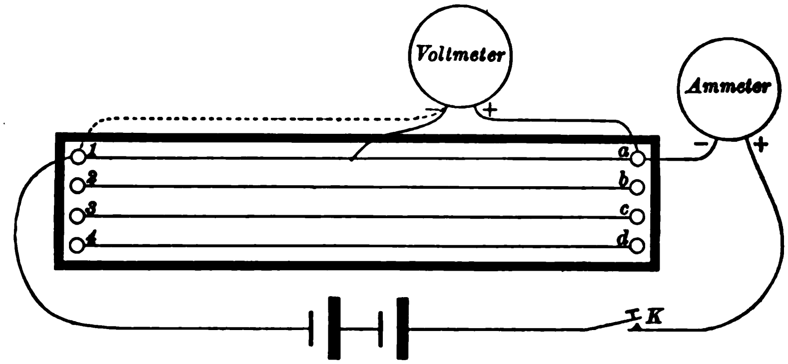


FIG. 63

3y Ohm's law, the resistance ıy portion of a circuit is given ıe equation

$$\text{istance} = \frac{\text{potential difference}}{\text{current}},$$

$$\text{Ohms} = \frac{\text{volts}}{\text{amperes}}.$$

Compute and record the resist- of the 50 cm. of wire.

b) Take observations with the ıeter connected across the 100 cm. of wire and compute its resistance. Call this resistance R_1.

c) State the law proved by I, (*a*) and I, (*b*).

I. **Diameter.** (*a*) Determine the resistance of 100 cm. of No. 24 German-silver wire (wire 2 of 63). Call this resistance R_2.

b) See Appendix B for diameter of wires used or measure them with a micrometer caliper.

c) Compute the ratios indicated in the data record.

d) State the law proved by these ratios.

II. **Material.** (*a*) Determine the resistance of 100 cm. of No. 30 iron wire (wire 3 of Fig. 63). this resistance R_3.

b) Find the resistance of 100 cm. of No. 30 copper wire (wire 4 of Fig. 63). Call this resistance R_4.

c) The resistance of iron wire is how many times that of copper wire of the same diameter and h? (Compare III, (*a*) and III, (*b*).)

'he resistance of German-silver wire is how many times that of copper wire of the same size? ıpare I, (*b*) and III, (*b*).)

V. **Series connection.** (*a*) Join the left-hand ends of wires 2 and 3 with a piece of No. 16 or 18 copper wire. (The resistance of this piece is so small (see Appendix B) that it may be ected.)

Connect the two ends *b* and *c* into the circuit and determine the joint resistance of the two wires ries.

b) What is the sum of the resistances of wires 2 and 3 as determined in II, (*a*) and III, (*a*)?

c) Compare this sum with the joint resistance in series determined in IV, (*a*).

d) State the law for series connection.

'. **Parallel, or shunt, connection.** (*a*) Join the left-hand ends and also the right-hand ends of ; 2 and 3 with pieces of No. 16 or No. 18 copper wire. Send the current in at *b* or *c* and out at 3. Connect the voltmeter across the two wires thus connected in parallel in the circuit. Deter- their joint resistance in parallel.

b) Determine the joint resistance of wires 1, 2, and 3 in parallel.

(*c*) Check the result found in (*a*) by use of the equation $\frac{1}{R}=\frac{1}{R_2}+\frac{1}{R_3}$. (See textbook.)

(*d*) Check the result found in (*b*) by the equation $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$.

Questions. ***a.*** With a given "head" of water in a standpipe, how will the quantity of water per second which can flow out of one main compare with that which can flow out of another main of twice the diameter when the speeds with which the water flows along the mains are the same in both cases?

b. With a given difference in electrical pressure (P.D.), how will the *quantity of electricity per second,* or *current,* which will flow through one wire compare with that which will flow through another wire of the same length and material but of twice the diameter?

c. Given three 10-ohm coils. Show by diagram how you would connect them into an electrical circuit so as to introduce 15 ohms into the circuit.

d. What is the joint resistance of three coils of 5, 10, and 15 ohms, respectively, when connected in series? when connected in parallel?

RECORD OF EXPERIMENT

Wire	Length and Number	P.D. in Volts	Current in Amperes	Resistance in Ohms
I. (*a*) One-half wire 1, German silver	50 cm. No. 30			
(*b*) Wire 1, German silver	100 cm. No. 30			R_1
II. (*a*) Wire 2, German silver	100 cm. No. 24			R_2
III. (*a*) Wire 3, iron	100 cm. No. 30			R_3
(*b*) Wire 4, copper	100 cm. No. 30			R_4
IV. (*a*) Wires 2 and 3 (series)				
V. (*a*) Wires 2 and 3 (parallel)				
(*b*) Wires 1, 2, and 3 (parallel)				

II. (*c*) $\left(\frac{\text{Diameter of wire 2}}{\text{Diameter of wire 1}}\right)^2$ = ...; $\left(\frac{\text{resistance of wire 1}}{\text{resistance of wire 2}}\right)$ = ...

III. (*c*) $\frac{\text{Resistance of iron}}{\text{Resistance of copper}}$ = ...; $\frac{\text{resistance of German silver}}{\text{resistance of copper}}$ = ...

IV. (*c*) $R_2 + R_3$ = ...ohms; joint resistance (series), IV, (*a*) = ...ohms.

V. (*c*) $\frac{1}{R}=\frac{1}{R_2}+\frac{1}{R_3}$, $\therefore R$ = ... ohms; joint resistance (parallel), V, (*a*) = ...ohms

(*d*) $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$, $\therefore R$ = ... ohms; joint resistance (parallel), V, (*b*) = ... ohms

EXPERIMENT 32 A

TO MEASURE AN UNKNOWN RESISTANCE BY MEANS OF WHEATSTONE'S BRIDGE AND TO FIND HOW THE DIAMETER AND MATERIAL OF A WIRE AFFECT ITS RESISTANCE

If a current is made to divide, as at a (Fig. 64), so that part of it flows along the branch abc and part along the branch adc, then there will be a continual fall in potential in going from a to c over each branch. Hence for any point b in one branch there must be in the other branch a corresponding point d at which the same potential exists. If these two points are connected through a galvanometer G, no current will flow through this galvanometer, since the same electrical pressure exists at b as at d. If the end of the connecting wire is moved a little to the right of d, a current will flow in one direction through G; while if it is moved a little to the left, a current will flow through G in the opposite direction. Hence, in order to find experimentally the point d which has the same potential as the point b, we have only to move the end of the galvanometer wire along the branch adc until we find a point at which the galvanometer shows no deflection. When this point has been found, the resistance of the four branches $ad (= P)$ dc $(= Q)$, $ab (= R)$, and $bc (= X)$ may be proved to be related in the following way:

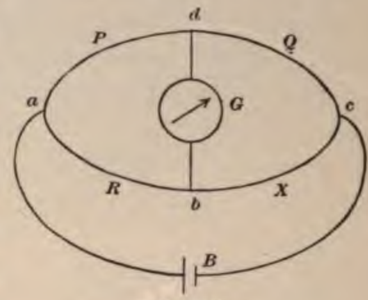


FIG. 64

$$P/Q = R/X.$$

To prove that this is so, we have only to apply Ohm's law. For if PD_1 represents the potential difference between a and d, and PD_2 that between d and c, then, since b and d have the same potential, PD_1 will also represent the potential difference between a and b, and PD_2 that between b and c. Now by Ohm's law, since the same current C_1 is flowing through ad and dc, we have $C_1 = PD_1/P = PD_2/Q$, or $PD_1/PD_2 = P/Q$. Similarly, on the lower branch, $PD_1/PD_2 = R/X$. Therefore $P/Q = R/X$ and $X = Q \times R/P$.

(a) Stretch No. 30 German-silver wire between a and c, as in Fig. 65, place a meter stick beneath it, and then connect a simple or a dry cell B to the terminals a and c. Between the binding posts a and b insert some known resistance, say a 1-ohm coil. Between b' and c insert a 3-m. coil of No. 30 copper wire. The brass strap between b and b' has a negligible resistance, so that the whole of it may be considered as the point b of Fig. 64. Connect to the binding post at m one terminal of a D'Arsonval galvanometer G. This instrument is precisely that shown in Fig. 56, save that a slender pointer must be inserted in the place provided for it for the sake of making small deflections more easily observable.

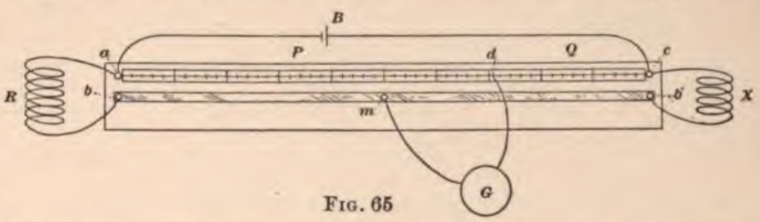


FIG. 65

Touch the free terminal of the galvanometer at a number of points along the wire ac until you find that point at which the galvanometer shows no deflection on making contact. Since the wire ac is uniform, the ratio of the resistances P and Q is simply the ratio of the lengths $ad (= l_1)$ and $dc (= l_2)$. Hence,

$$l_1/l_2 = R/X \quad \text{or} \quad X = R \times l_2/l_1.$$

(b) In the same way measure the resistance of exactly 50 cm. of No. 30 iron wire, and by the law of lengths calculate from the result the resistance in ohms of such a wire 3 m. long.

(*c*) In the same way measure the resistance of exactly 25 cm. of No. 30 German-silver wire, and compute from the result the resistance of such a wire 3 m. long.

(*d*) Measure, also, the resistance of exactly 50 cm. of No. 24 German-silver wire, and compute from the result the resistance of such a wire 3 m. long.

Questions. *a.* The resistance of an iron wire is how many times that of a copper wire of the same diameter and length?

b. The resistance of a German-silver wire is how many times that of a copper wire of the same length

c. The diameter of No. 24 wire is twice that of No. 30 wire (see Appendix B). How does the resistan of a wire depend upon its diameter?

RECORD OF EXPERIMENT

	l_1 IN CENTIMETERS	l_2 IN CENTIMETERS	R IN OHMS	X IN OHMS	RESISTANCE OF 300 CM.
(*a*)					
(*b*)					
(*c*)					
(*d*)					

$\dfrac{\text{Resistance of iron}}{\text{Resistance of copper}} = \ldots\ldots$; $\dfrac{\text{resistance of German silver}}{\text{resistance of copper}} = \ldots\ldots$

$\left(\dfrac{\text{Diameter of No. 24 wire}}{\text{Diameter of No. 30 wire}}\right)^2 = \ldots\ldots$; $\dfrac{\text{resistance of 300 cm. of No. 30 German-silver wire}}{\text{resistance of 300 cm. of No. 24 German-silver wire}} = \ldots\ldots$

EXPERIMENT 33

HOW DOES THE RESISTANCE OF GALVANIC CELLS DEPEND UPON THE AREA OF THE PLATES IMMERSED, THE DISTANCE BETWEEN THE PLATES, AND THE METHOD OF CONNECTING THEM?

I. **Area of plates immersed.** (*a*) Connect an improvised Daniell cell* to the single turn of coarse pper wire of the galvanoscope or to an ammeter. Record the reading of the instrument used.

(*b*) Lift the plates gradually out of the glass and record the effect. Since, as proved in Exp. 31, e E.M.F. is not diminished by decreasing the area of the plates immersed, what do you conclude, om Ohm's law, must have changed in the circuit as the plates were lifted? How, then, is the ***internal sistance*** affected by the size of the plates?

For a battery circuit Ohm's law must then be

$$C = \frac{\text{E.M.F.}}{R_e + R_i},$$

ere R_e is the resistance of the circuit external to the battery, and R_i is the internal resistance the battery.

II. **Distance between plates.** Dispense with the plate holder of the cell. Press the wires firmly ainst the plates and record the reading of the instrument used, first, when the plates of the cell are ought as close together as possible, that is, on adjacent sides of the porous cup, and second, when e plates are held as far apart as possible in the cell. How is R_i affected by the distance between e plates?

III. **Internal resistance of cells in series.** (*a*) Connect a single Daniell cell to the single turn coil the galvanoscope or to an ammeter. (In this and succeeding parts of the experiment, if the galnoscope is used, the compass should be slipped along in the frame until the deflection at first is not re than 16°.) The external resistance of the circuit is now very small and, without appreciable or, may be considered equal to zero, so that under these conditions $C = \frac{\text{E.M.F.}}{R_i}$.

Now introduce enough German-silver wire in series with the circuit to reduce the current nmeter reading or deflection, depending on the instrument used) to one half its former value. asure the length, in centimeters, of the German-silver wire thus introduced and find its resistance ohms. (1 cm. of No. 30 German-silver wire has a resistance of .0621 ohms.)

Since the introduction of the German-silver wire halved the current, the resistance of the circuit st have been doubled. Hence, by the equation $C = \frac{\text{E.M.F.}}{R_e + R_i}$, the resistance R_e of the German-silver re introduced into the circuit must be equal to the internal resistance R_i of the cell. Call this istance $(R_i)_1$.

(*b*) In the same way find the internal resistance of a second Daniell cell, expressed first in centiters of No. 30 German-silver wire and then in ohms. Call this resistance $(R_i)_2$.

(*c*) By the same method find the combined internal resistance of the two cells joined in series. l this resistance R_s.

(*d*) How does R_s compare with the sum of $(R_i)_1$ and $(R_i)_2$.

* For these cells use a saturated solution of copper sulphate outside the porous cup and a 10% solution of sulphuric acid de the porous cup.

At the close of the day's work place the porous cups in a battery jar, cover with water, and add from 5 to 10% as much ic acid as there is water. The nitric acid is to remove the copper deposited in the pores of the cup. The internal resistance ells when made as above will seldom be more than 4 ohms and often less than 1 ohm.

IV. Internal resistance of cells in parallel. (*a*) By the above method find the joint internal resistance of the two cells connected in parallel. Call their joint resistance in parallel R_p.

(*b*) Compare R_p as thus obtained with R_p as computed by the formula for resistances in parallel; namely,

$$\frac{1}{R_p} = \frac{1}{(R_i)_1} + \frac{1}{(R_i)_2}, \quad \text{or} \quad R_p = \frac{(R_i)_1 \times (R_i)_2}{(R_i)_1 + (R_i)_2}.$$

Questions. ***a.*** Why is the carbon in a dry cell made about an inch in diameter rather than the size of lead pencil?

b. Commercial storage batteries are made with large plates placed close together. Would you expect their internal resistance to be large or small? Why?

c. If n cells each having the same internal resistance R_i were connected in series, what would be their joint internal resistance?

d. If the n cells were connected in parallel, what would be their joint internal resistance?

e. How should cells be connected in order to get as large a current as possible, if the external resistance is small? if the external resistance is large?

RECORD OF EXPERIMENT

I. (*a*) Deflection of compass for large plates = ..., (*b*) for small plates = ...

or (*a*) Ammeter reading for large plates = ..., (*b*) for small plates = ...

II. (*a*) Deflection of compass, plates close = ..., (*b*) plates far apart = ...

or (*a*) Ammeter reading, plates close = ..., (*b*) plates far apart = ...

	R_i in Centimeters of No. 30 German-Silver Wire	Internal Resistance in Ohms
III. (*a*) Cell 1		
(*b*) Cell 2		
(*c*) Cells 1 and 2 in series		
IV. (*a*) Cells 1 and 2 in parallel		

III. (*d*) $(R_i)_1 + (R_i)_2$ = ... ohms; joint resistance in series, III, (*c*) = ... ohms.

IV. (*b*) $\frac{(R_i)_1 \times (R_i)_2}{(R_i)_1 + (R_i)_2}$ = ... ohms; joint resistance in parallel, IV, (*a*) = ... ohms.

EXPERIMENT 34

WHICH WOULD YOU INSTALL IN YOUR HOME, TUNGSTEN LAMPS OR CARBON-FILAMENT LAMPS? WOULD YOU CONNECT THEM IN SERIES OR IN PARALLEL?

In answering the first question one must take into consideration the initial cost, the cost of maintenance, and the cost of operation of the lamps. The initial cost of tungsten lamps (Mazda lamps) is somewhat more than the initial cost of the ordinary carbon-filament lamps. This extra cost of tungsten lamps must then be at least offset by a lower cost of operation if tungsten lamps are to be chosen.

I. Comparison of cost of operation. Connect four lamps in parallel as in Fig. 66. Introduce an ammeter in series in the "line" and connect a voltmeter across the line.

Caution. Do not turn on the current until an instructor has O.K.'d your electrical connections. A mistake might completely ruin an electrical instrument.

Lamps *a* and *b* are tungsten lamps whose ratings are about 20 watts and 40 watts respectively. Lamps *c* and *d* are ordinary carbon-filament lamps whose ratings are about 55 watts and 100 watts respectively. If the candle powers of the lamps are not marked on them, consult the instructor.

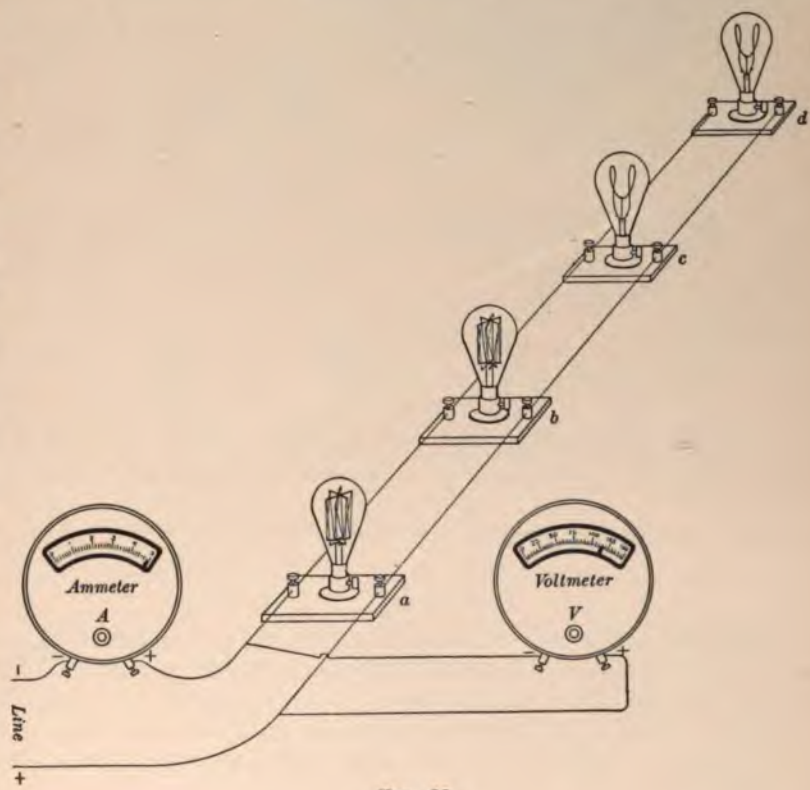


Fig. 66

Turn on lamp *a*. Record the voltmeter and ammeter readings. From these readings compute the number of watts required to operate the lamp, and compare with the voltage marked upon it. Watts = volts × amperes. Calculate also the number of watts required to produce one candle power.

Turn off lamp *a* and turn on lamp *b* and then make a similar set of observations and calculations for lamp *b*.

Make similar tests with lamps *c* and *d*.

Compute with the aid of Ohm's law the resistance, when hot, of each of the lamps *a*, *b*, *c*, and *d* and call these resistances R_1, R_2, R_3, and R_4 respectively. Do not record more than three significant figures in these results.

II. How to connect lamps in a lighting circuit. (*a*) Turn on all the lamps as you now have them connected (that is, in parallel, as in Fig. 66). Record the readings of the voltmeter and the ammeter and from these readings compute the joint resistance, when hot, of the four lamps in parallel. Call their joint resistance R_p.

Compute R_P also by use of the equation* $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$.

Compare the two values of R_P obtained above.

(*b*) Now connect the four lamps in series with the ammeter as in Fig. 67 and record its readings. Then record the voltmeter reading when connected successively across each individual lamp, and also when connected across all four lamps.

Again compute the resistance of each lamp under these conditions; that is, when the lamp filaments are much colder.

Also compute the resistance R_S of the four lamps in series, first from the voltmeter and ammeter readings and then by use of the equation for resistances in series, that is, $R_S = R_1 + R_2 + R_3 + R_4$.

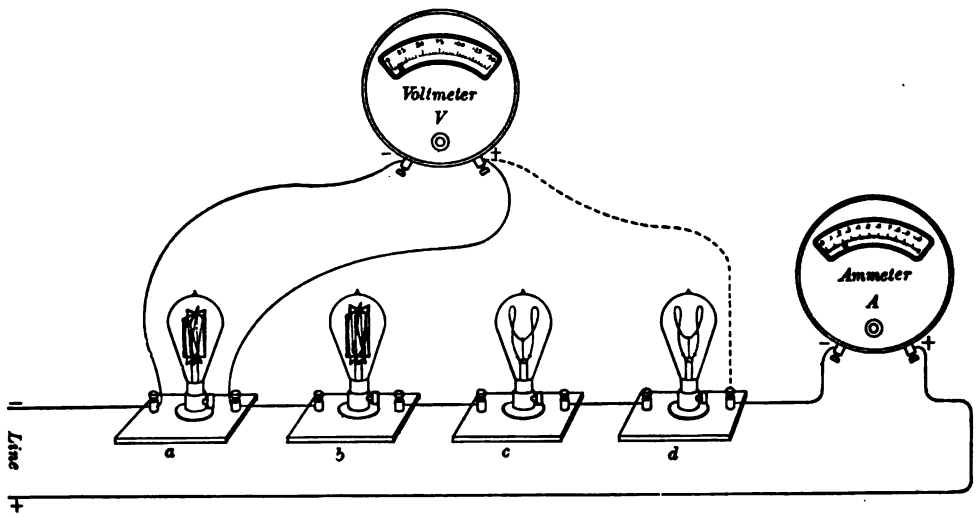


FIG. 67

Questions. ***a.*** The life of either the tungsten or the carbon-filament lamp is from 1000 to 2000 hr. Allowing for breakages, assume that their life is 500 hr. At the price charged by your local power plant per kilowatt hour for electricity what would it cost to operate one 16-candle-power tungsten lamp (Mazda) for the 500 hr. What would it cost to operate one carbon-filament lamp of the same candle power for the same length of time? What then is the saving in the cost of operation of one lamp during its life (assumed to be 500 hr.)?

b. Is the extra initial cost of tungsten lamps more than offset by a lower cost of operation? If so, how much? (Before answering this question ask your dealer to quote you prices on Mazda lamps and also on ordinary carbon-filament lamps of say 16 candle power in each case.)

c. Is the resistance of a carbon filament increased or decreased by increasing its temperature?

d. How is the resistance of tungsten affected by increasing its temperature?

e. Make a diagram of the connections for lighting three rooms of a house with four lamps in each room.

* The following is a practical way of solving a similar equation. If, for example, four lamps have resistances of 220, 109, 605, and 297 ohms respectively, their joint resistance, R_P, when connected in parallel, is given by

$$\frac{1}{R_P} = \frac{1}{220} + \frac{1}{109} + \frac{1}{605} + \frac{1}{297}$$
$$= .00455 + .00917 + .00166 + .00336$$
$$= .01874.$$
$$\therefore R_P = \frac{1}{.01874} = 53.4 \text{ ohms.}$$

EXPERIMENT 34 (*Continued*)

RECORD OF EXPERIMENT

I.

Lamp	Volts	Amperes	Watts	Candle Power	Watts per Candle Power	Resistance (when Hot)
(*a*)						$R_1 =$
(*b*)						$R_2 =$
(*c*)						$R_3 =$
(*d*)						$R_4 =$
(*a*), (*b*), (*c*), and (*d*), in parallel			*	*	*	$R_P =$

II.

Lamp	Volts	Amperes	Resistance (when Colder)
(*a*)			$R_1 =$
(*b*)			$R_2 =$
(*c*)			$R_3 =$
(*d*)			$R_4 =$
(*a*), (*b*), (*c*), and (*d*), in series			$R_S =$

R_P, from $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$,
= .... ohms.

R_P, from I, = ... ohms.

(For above, use values of R_1, R_2, etc., when hot.)

R_S, from $R_S = R_1 + R_2 + R_3 + R_4$,
= .... ohms.

R_S, from II, = ... ohms.

(For above, use values of R_1, R_2, etc., when colder.)

* These spaces to be left blank by the student.

EXPERIMENT 34 A

HEATING EFFECTS OF THE ELECTRIC CURRENT

The application of electric currents to heating is daily becoming of greater commercial importance. Our highest temperatures are obtained in the electric arc and the electric furnace. Electric disk stoves, teakettles, egg cookers, toasters, chafing dishes, percolators, grills, water heaters, immersion coils, flatirons, curling irons, mangles, foot warmers, radiators, shaving mugs, milk warmers, and sterilizers are some of the household conveniences. Electric soldering pots, soldering irons, glue cookers, glue pots

FIG. 68

FIG. 69

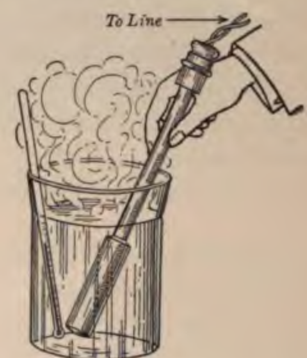


FIG 70

for cabinet makers, melting pots for lead alloys, instantaneous heaters for soda fountains, mangles, fluting irons, automobile tire vulcanizers, and electric welders are also some of the commercial applications of heating by the electric current.

The designer and the producer of these useful appliances are interested in increasing the percentage of the energy of the electric current which is transformed into heat available for the intended purpose. The ratio of this available heat energy (or output) to the electric energy (or input) for any of these devices is its efficiency.

The consumer or user of these appliances is interested not only in their efficiency and cost of operation but also in their convenience.

Heating water with the electric current. Pour 1 lb. of cold water into the teakettle used in Exp. 18 and place it on the electric disk heater of Fig. 68. Connect an ammeter in series with the heater and line and a voltmeter across the line, as in Fig. 71.

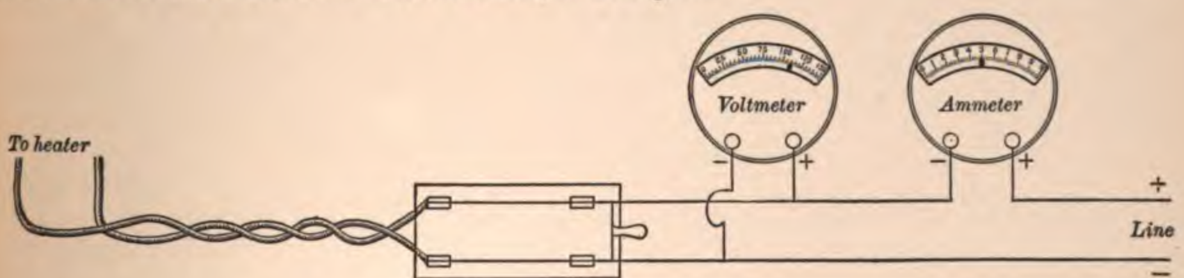


FIG. 71

Caution. Do not turn on the current until an instructor has O.K.'d the arrangement of your apparatus.

Now turn on the current and simultaneously observe the exact time that it is turned on.

Record the voltmeter and the ammeter readings every minute until the water boils. Then turn off the current, noting the exact time that it is turned off.

From the average voltmeter and ammeter readings and from the time compute the number of kilowatt hours of electricity used.

At the local price per kilowatt hour for electricity, compute the cost of heating 1 qt. of water to the boiling point.

Compare this cost to the cost of heating 1 qt. of water to the boiling point with the gas stove (see Exp. 18 A).

Practical efficiency of the electric heater. Pour 500 g. of water at a temperature of 12° C. or 15° C. below room temperature into the teakettle and place a thermometer in the water.

Turn on the current; stir the water continually with the thermometer; observe the exact time when the water attains a temperature which is 10° C. below room temperature; and again observe the time when the water attains a temperature which is 10° C. above room temperature.

The practical efficiency is then the ratio of the number of calories of heat received by the water to the number of calories of heat produced by the heating effect of the electric current in the coils of the stove; that is,

$$\text{Practical efficiency} = \frac{\text{weight of water} \times \text{change in temperature}}{.24 \times \text{watts} \times \text{seconds}}.$$

Questions. ***a.*** If the teakettle were covered with asbestos, would the combined efficiency of the stove and teakettle be higher? Why?

b. If the electric teakettle of Fig. 69 is used, should its efficiency be higher than that of a teakettle used with the electric disk stove of Fig. 68? Why? (The teakettle of Fig. 69 has a "self-contained heating coil.")

c. How would you expect the efficiency of the immersion heater shown in Fig 70 to compare with the efficiency of either of the other heaters shown? Give reason for your answer.

d. In obtaining the "theoretical efficiency" the water equivalent of the teakettle would have to be taken into account. Would the "theoretical efficiency" be higher or lower than the "practical efficiency"?

EXPERIMENT 35

ELECTROLYSIS AND THE STORAGE BATTERY

I. Electrolysis of water. Bare the ends of two pieces of copper wire and wrap each about the head of a wire nail.* Connect the other ends of the wires to the terminals of two dry cells joined in series. Dip the ends of the nails into a dilute solution of sulphuric acid like that used in Exp. 28. Is the nail from which the bubbles appear first and most abundantly connected to the + or to the − pole of the battery; that is, to the carbon or to the zinc? This gas which is given off most abundantly is hydrogen; that which appears at the other nail is oxygen. In order to account for these effects we assume that when the molecules of sulphuric acid (H_2SO_4) go into solution in water they split up into two electrically charged atoms, or ions, of hydrogen and one oppositely charged ion of SO_4. It was this hydrogen which, according to this hypothesis, appeared at one nail while the SO_4 went to the other and there gave up an atom of oxygen. If this hypothesis is correct, must the hydrogen ion in solution carry a + or a − charge in order to appear upon the nail upon which you observed it? What kind of a charge must the SO_4 ion carry?

II. Electroplating. Remove the nails and attach each bare wire to some sort of improvised metal clip (ordinary paper fasteners are excellent). In each of these clips place a nickel and dip the lower half of each into a solution of copper sulphate ($CuSO_4$). About which nickel do you now see bubbles, the one connected to the + or the one connected to the − pole of the battery? (The former is called the anode, the latter the cathode.) These bubbles are oxygen. After about a minute remove the nickels and dry them with a cloth. Record what has happened. Decide from your results whether the copper ions of the copper sulphate solution carry + or − charges.

Interchange the nickels between the two clips and repeat the above operations. Record the results. (If you wish to restore your nickels quickly to their original condition, dip them for an instant in strong nitric acid and rub with an old cloth.)

III (*a*). The storage battery.† Arrange a simple cell in the manner shown in Fig. 72, *a* and *b* being the copper and the zinc strip to which are connected the terminals of an improvised voltmeter consisting of the 1000-ohm resistance coil *R* and the galvanoscope *V*, with the compass beneath its high-resistance coil. *A* is an improvised ammeter consisting of another galvanoscope with the compass beneath the 25-turn coil of coarse wire; *r* is a resistance of about 100 ohms (use for it 4 m. of No. 36 German-silver wire, wound on a spool of insulated wire or held on the frame of Fig. 63 if bare wire); *B* is a battery of two dry cells connected in series but *not* joined, at first, to the terminals *m* and *n* of the cell circuit. Move the compass of *V* until the deflection is 8° or 10°. This amount of deflection then represents the E.M.F. of a copper-zinc sulphuric acid cell (approximately 1 volt).

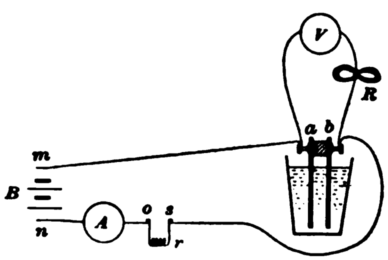


FIG. 72

Now replace the zinc and the copper strip by two strips of sheet lead. Does the voltmeter *V* now indicate any E.M.F.? Explain the reason. Next connect *m* and *n* to the terminals of the dry battery *B*, and as soon as the needles are sufficiently quiet, record the deflections shown by both *A* and *V*; then watch both needles carefully for about two minutes and record the readings, expressing the reading of *A* simply in scale divisions, but that of *V* in both scale divisions and volts.

* Platinum electrodes are better, but they are less convenient and much more expensive.

† Two sets of students are expected to work together on this experiment, and where low-reading voltmeters and ammeters are available, the method of III (*b*) will be found somewhat shorter than that of III (*a*) and just as satisfactory.

Now short-circuit the terminals *o* and *s* of the resistance *r* by pressing a strip of metal against the two binding posts *o* and *s* or by connecting them with a copper wire. Watch the plates and note the hydrogen appearing in considerable quantity about the cathode, while but little oxygen appears about the anode. After the current has been running through the short circuit on *r* for about two minutes lift the plates from the liquid. Do you see a faint reddish deposit upon the anode where the oxygen would naturally have appeared? If not, let the current run a little longer and observe again. This deposit is *lead peroxide* (PbO_2). Why, then, did so little oxygen gas appear about the anode?

Replace the plates in the acid, take away the shunt from *os*, and record the reading of *V*. By how many volts is it now larger than it was when *m* and *n* were first joined to *B*? Disconnect *m* and *n* from *B* and observe how many volts of E.M.F. have been developed between the lead plates. Now watch the ammeter as you join *m* and *n* to each other. What is the direction of the observed current with reference to that which the battery sent through the ammeter? Watch the voltmeter and the ammeter for two minutes while the *storage cell* is discharging. In view of this back E.M.F. which the experiment has shown was developed in the lead cell by the deposit of lead peroxide on the anode, explain why, during the *charging* of the storage cell, the voltmeter deflection *rose*, while that of the ammeter *fell*. From your experiment decide how many volts are required to charge a storage cell.*

III (*b*). The storage battery. Make a cell like that shown in Fig. 73, with two well-cleaned lead plates dipped into a solution made of one part sulphuric acid to ten parts water.

Connect a voltmeter across the cell and see if it produces any E.M.F.

To charge the cell connect it in series with a resistance of about 5 or 6 ohms (about 1 m. of No. 30 German-silver wire), a low-reading ammeter, and two dry cells. At the same instant in which the last connection of the charging circuit is made, one student should record the voltmeter reading and another the ammeter reading. Record the reading of each meter every ten or fifteen seconds for two minutes.

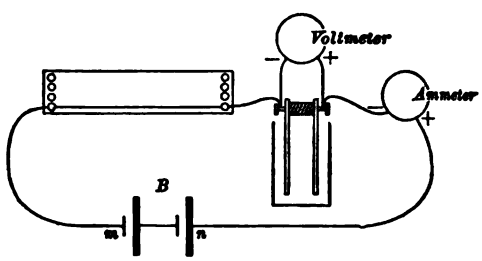


FIG. 73

Now increase the charging current by connecting the ends of a meter of No. 24 copper wire to the binding posts which hold the German-silver wire. Watch the plates and note the hydrogen appearing in considerable quantity about the cathode, while but little oxygen appears about the anode. After the increased charging current has been running for about two minutes lift the plates from the liquid. Do you see a faint reddish deposit upon the anode where the oxygen would naturally have appeared? If not, let the current run a little longer. This deposit is *lead peroxide* (PbO_2). Why, then, did so little oxygen appear about the anode?

Replace the plates in the acid, take away the copper wire which was shunted across the German-silver wire, and record the voltmeter reading. By how many volts is it now larger than it was when *m* and *n* were first joined to *B*? Disconnect *m* and *n* from *B* and observe how many volts of E.M.F. have been developed between the lead plates. Now watch the ammeter as you join *m* and *n* to each other. What is the direction of the observed current with reference to that which the battery sent through the ammeter? Watch the voltmeter and the ammeter for two minutes while the *storage cell* is discharging. In view of this back E.M.F. which the experiment has shown was developed in the lead cell by the deposit of lead peroxide on the anode, explain why, during the *charging* of the storage cell, the voltmeter deflection *rose*, while that of the ammeter *fell*. From your experiment decide how many volts are required to charge a storage cell.

* If you wish to repeat the experiment with the same lead plates, clean them first very thoroughly with sandpaper.

EXPERIMENT 36

INDUCED CURRENTS

I. Induction of currents by magnets. (*a*) Set up the D'Arsonval galvanometer (Fig. 74) and insert in the place provided for it a slender wire or broom-corn pointer in the manner shown in the figure. Short-circuit a simple cell by means of a few feet of copper wire; then to the galvanometer terminals touch wires which are connected to the cell and note the direction of deflection. (The object of the short-circuiting is to prevent a too violent throw of the coil.) Record the terminal (right or left) of the galvanometer at which the current entered it when the deflection was in a given direction (right or left). This will enable you henceforth to know at which terminal any current enters your galvanometer, as soon as you observe the direction of deflection. Connect to the galvanometer a 600- or 700-turn coil *A* of No. 27 copper wire. Take particular pains to scrape the ends of all wires which are to be joined, and to twist the scraped ends firmly together.

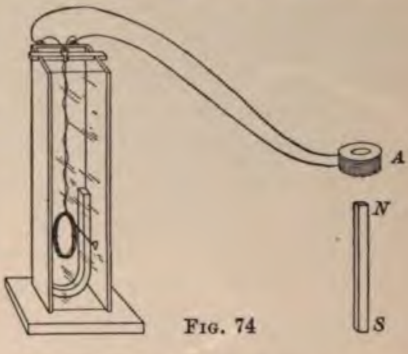


Fig. 74

Thrust the coil *A* suddenly over the north pole of the bar magnet and note and record the direction and the approximate amount of the deflection of the end of the pointer attached to the coil. A paper scale supported between the walls beneath the pointer will enable you to estimate amounts.

(*b*) From the direction of the deflection determine the direction of the current induced in the coil of wire thrust over the pole. While this induced current was flowing, did it make the end of the coil — considered as a temporary magnet (see Exp. 30) — which was approaching the *N* pole, an *N* or an *S* pole?

(*c*) Suddenly withdraw the coil from the magnet. Note and record as before the direction and amount of deflection. How does the direction and amount of the induced current now compare with that found in (*a*)? Is the end of the coil which leaves the magnet last of the same sign as the pole of the magnet or of unlike sign?

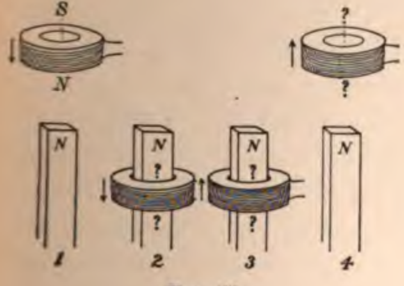


Fig. 75

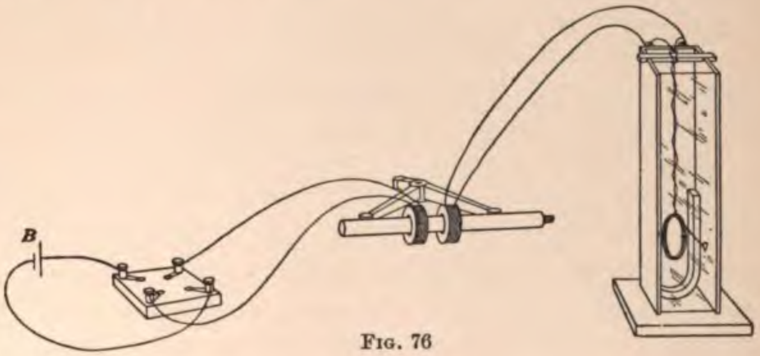


Fig. 76

(*d*) Draw in your notebook four figures like those shown in Fig. 75 and insert in each the signs of the poles of the coil due to the induced current, when the coil is in the four positions indicated in the figures and moving in the directions indicated by the arrows.

(*e*) Repeat the same experiments with the *S* pole of the magnet and observe in each case the direction of deflection and the direction of the current induced in the coil. Is the nature of the induced magnetism of the coil *A* in every case such as to *oppose* or to *assist* the motion of the coil?

II. Induction of currents by electromagnets. (*a*) Slip the 700-turn coil used in I over an iro bar (for example, one of the tripod rods) and connect it through a commutator with a battery *B* c one or two dry cells, in the manner shown in Fig. 76. Place a second similar coil over this bar an connect it with the D'Arsonval galvanometer, as shown. Now *make* the circuit by inserting the uppe part of the commutator, and record the effect produced upon the needle. From the direction o deflection of the pointer, find the direction in which the current flowed around the iron core in th coil attached to the galvanometer (the so-called *secondary*). Was the induced current in the same or in the opposite direction to that in which the current from the cell is circulating around the core in the *primary?* What connection do you find between this experiment and I?

(*b*) Remove the commutator top and thus *break* the circuit in the primary. Note the direction and amount of deflection and compare with that observed when the current was *made*. Compare the direction of the induced current in the secondary with that which was flowing in the primary. Is the current in the secondary circuit produced by the magnetism of the electromagnet or by changes in the magnetism of the electromagnet? Do the induced currents in every case tend to assist or to oppose the changes which are taking place in the magnetism of the core?

(*c*) Push up the base of the tripod into contact with the rod (Fig. 76), so that the magnetic lines can have a return *iron* path instead of a return *air* path. Observe the amount of the deflection at make or break and compare with the amount when the tripod base is removed. (The difference will not be large, but it will be easily observable.)

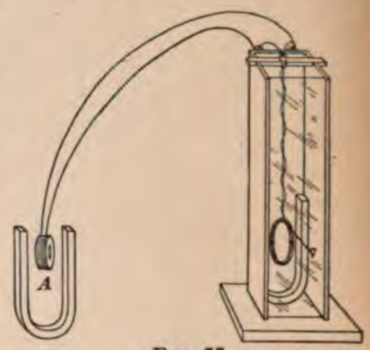


FIG. 77

III. Principles of the dynamo and the motor. (*a*) Hold the coil *A* between the poles of a horseshoe magnet (Fig. 77), and in such a position that its plane is *perpendicular* to a line joining the poles. Rotate quickly through 90°; that is, to a position in which its plane is *parallel* to the lines of force. Observe the direction of deflection of the suspended coil.

(*b*) After the pointer has come to rest, rotate the coil *A* 90° more and note and record the direction of deflection.

(*c*) Similarly, rotate the coil through the next two quadrants.

(*d*) If the coil were to be rotated continuously in this way, what portions of the rotation would produce a current in one direction and what in the opposite direction? In what position of the coil will the induced current change from one direction to the other?

(*e*) In a dynamo a coil is forced to rotate in the strong field of an electromagnet, and induced currents are produced. In a motor, currents are sent through a coil which is in a strong magnetic field, and the coil is forced to rotate. Point out the parts of the above apparatus which correspond to the dynamo and those which correspond to the motor.

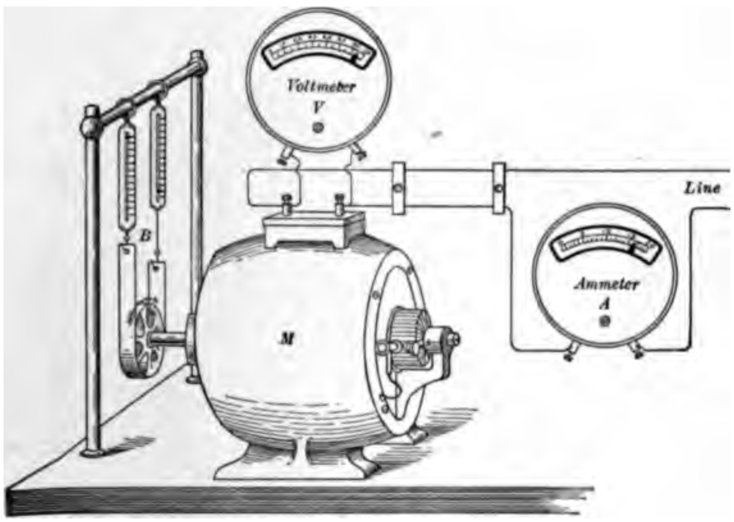
EXPERIMENT 37

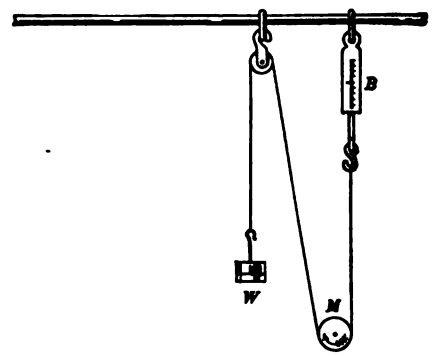
TO DETERMINE THE POWER AND EFFICIENCY OF AN ELECTRIC MOTOR

Connect the ammeter in series with the motor to measure the current through the motor, and the voltmeter in parallel with it to measure the P.D. across the motor (see Fig. 78).

For measuring the output of small motors having a grooved belt wheel, use the modification of the Prony brake shown at the right in Fig. 78.

Disconnect the brake belt to relieve the motor of its load. Close the switch and slowly move the lever of the starting resistance, or of the rheostat, so as to cut out the resistance in series with the motor.





Modification of Prony Brake

Fig. 78

Now attach the brake belt and increase the tension on it by raising the balance support until the speed is about 100 to 200 R.P.M. (revolutions per minute). In the modified form of Prony brake this is accomplished by increasing the weight *W*.

Let one student read the voltmeter and ammeter, another the speed indicator and stop watch, and another the balances.

The recorded voltmeter, ammeter, and balance readings should be the mean of several observations made during the same time that the number of revolutions for one minute are observed.

Stop the motor by opening the switch. Wrap a thread several times around the belt wheel and from the length of the thread and the number of turns determine the circumference of the wheel in feet.

The circumference in feet multiplied by the pull on the belt in pounds (pull on the belt = difference in the two balance readings, or else the single balance reading minus the weight) gives the number of foot pounds of work done by the motor in one revolution. This number of foot pounds per revolution multiplied by the R.P.M. gives the *output* of the motor in foot pounds per minute.

Express the *output* in horse power, remembering that 33,000 ft. lb. per minute = 1 horse power.

The *input*, or the rate at which energy is supplied to the motor by the electric current, expressed in watts, is equal to the number of volts P.D. across the motor multiplied by the current through the motor in amperes.

Express the *input* also in *horse power*, remembering that 746 watts = 1 horse power.

Calculate the efficiency of the motor; that is, the ratio of the output to the input.

Repeat the experiment, using a considerably higher speed and a smaller pull on the belt.

EXPERIMENT 37 (*Continued*)

Questions. *a.* Is the efficiency of a motor the same for different speeds?

b. Would its efficiency be higher if there were no atmosphere?

c. How does the heat generated in the armature and field windings ($H = .24\,C^2Rt$) affect the efficiency of the motor?

d. An electric automobile is run for five hours. During this time the motor delivers energy at an average rate of 2 H.P. If the motor has an efficiency of 90% and the storage batteries an efficiency of 75%, how much does it cost to charge the storage batteries sufficiently for this trip, if the cost of the electricity used in charging the batteries is four cents per kilowatt hour.

RECORD OF EXPERIMENT

Output

Circumference of belt wheel = ... ft.

Trial	Reading of Balance 1	Reading of Balance 2	Pull on Belt in Pounds	Foot Pounds per Revolution	R.P.M.	Foot Pounds per Minute	Horse Power
Low speed							
High speed							

Input

Trial	P.D. in Volts	Current in Amperes	Watts	Horse Power
Low speed				
High speed				

Efficiency at low speed = ... %

Efficiency at high speed = ... %

EXPERIMENT 37 A

A STUDY OF A SMALL MOTOR AND DYNAMO

I. Adjustment of the commutator. Swing the permanent field magnets away from the armature of the motor shown in Fig. 79. Connect one dry cell to the motor. With a small compass test the polarity of each end of the armature core for a complete revolution. Note the position of the armature when the polarity of its iron core changes.

In what position should the armature core be when its polarity changes if the ends are to be acted upon by the field magnets in such a way as to produce continuous rotation? Turn the toppiece which carries the brushes until the point of commutation, that is, the position where the insulating slits of the commutator pass under the brushes, is at the proper place.

II. Speed of rotation. (*a*) Now swing the permanent field magnets close to the armature and allow the motor to come to full speed. Then gradually swing the field magnets away from the armature and explain the result.

(*b*) With the field magnets close to the armature, observe the effect on the speed of the motor of reducing the current through the armature. This may be accomplished by placing a resistance

FIG. 79

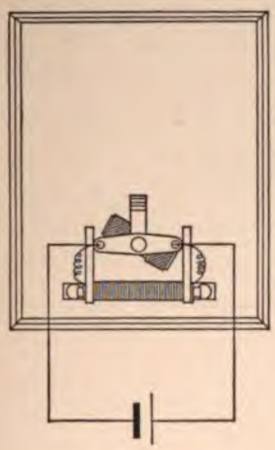


FIG. 80

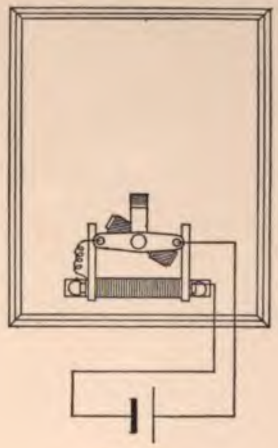


FIG. 81

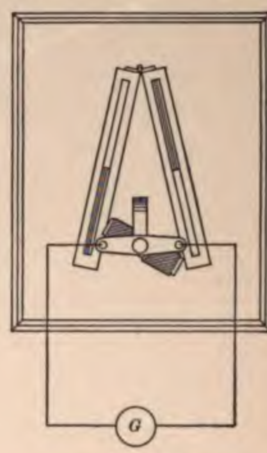


FIG. 82

box, or rheostat, of from 4 to 40 cm. of No. 36 German-silver wire in series in the circuit. Observe the effect on the speed when this resistance is increased from 1 ohm to 10 ohms, and again when it is decreased from 10 ohms to 1 ohm. Explain.

(*c*) The speed may also be changed by changing the point of commutation. To do this rotate the top which carries the brushes. How does this affect the speed, and why?

III. Direction of rotation. (*a*) Reverse the current through the armature. Observe and explain the effect observed.

(*b*) Turn each field magnet end for end. Explain the effect which doing this has on the direction of rotation.

(*c*) What effect would it have on the direction of rotation if the current through both the armature and the field were reversed? If in doubt try the experiment.

IV. Shunt-wound motor. (*a*) Swing the permanent field magnets out of the way and connect the electromagnet in parallel with the armature of the motor as in Fig. 80. Does all of the current flowing from the battery now pass through the armature as it did when used as in Fig. 79.

(*b*) Reverse the current from the battery. Observe and explain the effect, if any, on the direction of rotation.

V. Series-wound motor. (*a*) Connect the electromagnet attachment in series with the armature and the cells, as in Fig. 81. Does all of the current now flow through both the armature and the field magnets?

(*b*) Reverse the current. Explain what you observe.

VI. Dynamo. Remove the electromagnet attachment, swing the permanent magnets into place, and connect the motor to a galvanometer, as in Fig. 82. Try the following experiments.

(*a*) Rotate the armature in one direction and note the direction of deflection of the galvanometer.

(*b*) Rotate the armature in the opposite direction. Observe and explain the effect.

(*c*) Note the effect on the deflection of the galvanometer of swinging the permanent magnets away from and then toward the rotating armature. Explain.

(*d*) Is the deflection the same for all speeds of rotation? How does increasing the speed affect it?

(*e*) The current flowing through the galvanometer (and consequently the deflection in each of the above cases) was proportional to the induced E.M.F. Name as many factors as you can which affect the voltage produced by a dynamo.

EXPERIMENT 38

SPEED OF SOUND IN AIR

*A.** **Let the class be divided into two sections and placed from 500 to 1000 m. apart, the distance being measured by laying off from twenty-five to fifty times the length of a cord 20 m. long. Each group should be provided with a pistol, blank cartridges, at least one stop watch, and a thermometer. Let a member of one group raise and lower a handkerchief three times as a ready signal, and simultaneously with the last lowering let him fire a pistol. Let a member of the other group take with a stop watch the time which elapses between the flash and the report of the pistol. Then let the operations at the two stations be interchanged, in order to eliminate the effect of any wind which may be blowing. In this way take six or more observations, different members of the class timing the interval in turn. Observations which differ badly from the general average and which are evidently the result of awkward handling of the stop watch need not be included in the final mean. From this mean compute the velocity of sound at the temperature of the air.

B. If stop watches are not available, set up a heavy pendulum which beats seconds; attach some white object to it; set up a screen so that the pendulum can be seen only when it is passing the middle point of its swing; let one student stationed near the pendulum pound loudly on some sonorous object at each instant at which the pendulum crosses the middle point, and let the class move away until the beats of the hammer appear again to coincide with the passages of the pendulum. It is obvious that the distance from the class to the pendulum is numerically equal to the velocity of sound.

Questions. *a.* Assuming that the velocity of sound increases .6 m. per second when the temperature is increased 1° C., compute from your result the velocity of sound at 0° C.

b. What would be the difference in the velocity of sound on a hot summer day when the thermometer registers 40° C. and on a cold winter day when the thermometer registers – 25° C.

* Parts *A* and *B* of this experiment are intended as alternatives, the choice depending upon equipment.

EXPERIMENT 39

VIBRATION NUMBER OF A TUNING FORK*

(*a*) Smoke the glass plate *A* (Fig. 83) by holding it in the flame of burning gum camphor or in a gas flame.† Keep the plate moving back and forth so that it will not become overheated in one place and crack. Lay the plate on the board, smoked side up, and adjust the two styluses by means of the clamps *B* and *C* until they touch the plate lightly, very near each other in the line in which the motion is to take place. Set the tuning fork into vibration by striking it with a wooden mallet, or by bowing with a violin bow, and as soon thereafter as possible start the bob to vibrating, and draw the plate beneath the bob with such rapidity that the trace of three or four complete vibrations of the bob will appear on the plate.

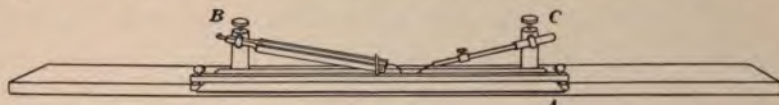


FIG. 83

(*b*) Count the number of vibrations of the fork corresponding to a full vibration of the bob; that is, the number of vibrations of the fork between the points *A* and *C* (Fig. 84), then between *B* and *D*, then between *C* and *E*, then between *D* and *F*, etc., estimating in every case to tenths of a vibration. Take a mean of these counts as the number of vibrations of the fork to one of the bob.

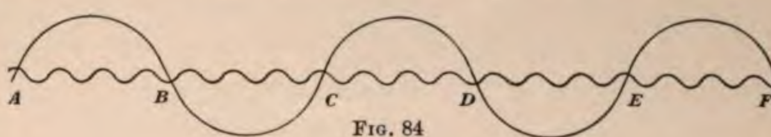


FIG. 84

(*c*) Repeat the observations on two other traces and take the mean of the three means as the correct number of vibrations of the fork to one of the bob.

(*d*) Get the rate of the bob by counting, with the aid of an ordinary watch, the number of vibrations which it makes in one or two minutes, or, if a stop watch is available, by taking the time of fifty vibrations of the bob.

(*e*) Compute the number of full vibrations made by the fork per second.

RECORD OF EXPERIMENT

	First Trace	Second Trace	Third Trace	Number of Vibrations of Bob
Vibrations between *A* and *C* =	....	....	....	....
Vibrations between *B* and *D* =	....	....	....	....
Vibrations between *C* and *E* =	....	....	....	....
Vibrations between *D* and *F* =	....	....	....	....
Means =	....	....	....	....

Final mean = ...

Number of vibrations of bob per second = ...

∴ rate of fork = ...

* One vibration-rate apparatus and fifteen glass plates will suffice for a class of thirty. It is recommended that the instructor make the traces and that the students take the measurements.

† Instead of smoking the plate, the authors often mix up a paste of whiting or chalk dust in alcohol and paint the plate with it. This brings out the trace quite as well, and the whiting is very much cleaner than lampblack.

EXPERIMENT 40

WAVE LENGTH OF A NOTE OF A TUNING FORK

(*a*) Let one student strike a C′ fork (that is, one which makes 512 vibrations per second) upon a block of wood, and then quickly hold it above the tube of Fig. 85 with the flat face of one prong just above the end of the tube. (Use the tube of Fig. 9, p. 7.) Let a second student raise and lower the vessel *A* while the fork is sounding, and note as accurately as possible the shortest length of the air column which gives a maximum resonance. Mark this position on the tube by means of a small rubber band. Test the correctness of the setting by several observations.

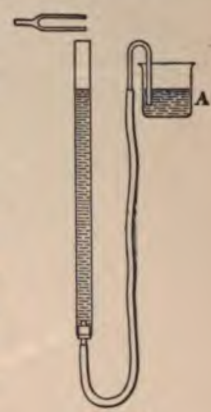


FIG. 85

(*b*) Locate in the same way a second position of resonance lower in the tube, and mark with a rubber band, as above. Since the distance between two positions of maximum resonance is exactly one-half wave length, twice the distance between the rubber bands will be equal to the wave length of the note sent forth by the sounding tuning fork. Compare this value of the wave length with that computed by dividing the speed of sound at the temperature of the room by the vibration number of the fork as marked upon it. (Speed of sound in air at 0° C. = 332 m. per second. It increases 60 cm. for each degree of rise in temperature.)

(*c*) Find in the same way the wave length of a fork one octave lower than the first.

Questions. ***a.*** Explain why the distance between the rubber bands is equal to one half of the wave length of the sound wave sent forth by the sounding tuning fork.

b. Show how the above experiment might be used for finding the velocity of sound.

c. Sound travels about four times as fast in hydrogen as in air. What would be the first resonant length for the C′ fork used above if the tube contained hydrogen?

d. Since the speed of sound is the same for notes of all pitches, what conclusion can you draw from your experiment in regard to the vibration frequencies of two notes which are an octave apart?

RECORD OF EXPERIMENT

	First Resonant Length l_1	Second Resonant Length l_2	Difference × 2 = l
Fork No. 1 =	....	....	....
Fork No. 2 =	....	....	....

Number of vibrations of fork No. 1 = ... ∴ calculated wave length = ...

Number of vibrations of fork No. 2 = ... ∴ calculated wave length = ...

EXPERIMENT 41

LAWS OF VIBRATING STRINGS

I. Effect of length on the vibration rate of a stretched wire. (*a*) Stretch a fine steel piano wire (No. 00) along the board *A* (Fig. 86), insert a bridge at *b*, and hang a pail having a capacity of at least six quarts over the pulley *p*. Pour water into the pail until the note given by the wire (best picked near the middle) is in unison with the note of the lowest fork provided; namely, C. Measure carefully the length of the wire between the fixed end and *b*.

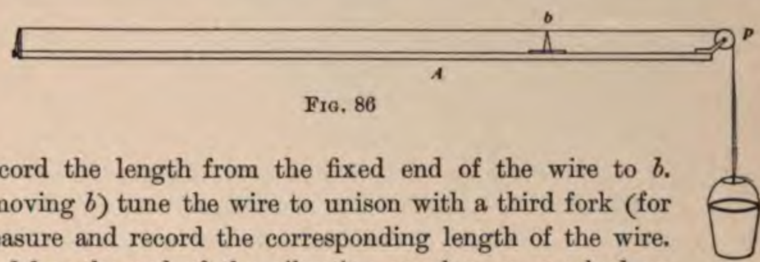


Fig. 86

(*b*) Move the bridge *b* until the note given by the wire is exactly in tune with a fork C′, an octave higher than the first one. Measure and record the length from the fixed end of the wire to *b*.

(*c*) In the same way (that is, by moving *b*) tune the wire to unison with a third fork (for example, G above middle C) and measure and record the corresponding length of the wire.

(*d*) From a study of the measured lengths and of the vibration numbers as marked on the forks find and state in your notebook the law connecting the rate of a vibrating string with its length when the tension is kept constant.

II. Effect of tension on the vibration rate of a stretched wire. (*a*) Set up side by side two boards like *A* (Fig. 86), both of which are provided with No. 00 piano wire. Place the bridges *b* at the same distance, say 60 cm., from the left end of each. Produce the same tension in the two wires by hanging from each a like weight (for example, a pail containing a small amount of water). The weights should be of such size as to produce in the plucked wires a low but perfectly distinct musical note. Bring the two wires into exact unison by adjusting the water in one of the pails until no beats are heard when the strings are sounded together. Find the exact tension on one of the wires by weighing the pail and water carefully with a spring balance. Produce the exact octave on the other wire by moving the bridge until the wire is only one half as long as at first. Bring the first wire into unison with it by adding water to the pail, leaving the length exactly as at first. Weigh the pail and water again, and find the ratio of the weights in the two cases. In order to double the rate, how many times has it been necessary to multiply the stretching force?

(*b*) Make the second wire just two thirds its original length, its tension still being kept constant. In what ratio will this change its vibration number? Adjust the amount of water in the pail hanging from the first wire until the two are in unison, and weigh on the spring balance again.

From the law suggested in (*a*) calculate what this last stretching weight should have been and see how well it agrees with the observed value.

Questions. ***a.*** For the high notes on a piano does the manufacturer use long or short wires? Why?
b. State in your notebook the laws deduced from I and II.

RECORD OF EXPERIMENT

I. Effect of length		**II. Effect of tension**	
Length of C wire	= .... cm.	First stretching weight	= .... g.
Length of C′ wire	= .... cm.	Second stretching weight	= .... g.
Length of G wire	= .... cm.	Second divided by first	= .... g.
Calculated length of C′ wire	= .... cm.	Third stretching weight (calculated)	= .... g.
Calculated length of G wire	= .... cm.	Third stretching weight (observed)	= .... g.

EXPERIMENT 42

LAWS OF REFLECTION FROM PLANE MIRRORS

I. To prove that the angle of incidence equals the angle of reflection. (*a*) Blacken one side of a strip of plate glass or a microscope slide; attach it by means of a rubber band to a small wooden block, and then set it on edge so that the line AC (Fig. 87), drawn on a sheet of paper, coincides with the plane of the unblackened face. The rear face is blackened in order to prevent reflection from that face and enable one to work with the light reflected from the front face alone. Set a pin at a point B against the face of the glass. Set another pin at any point P, and then, placing the eye so as to sight along B and P'', the image of P, set a third pin P' somewhere in this line of sight. Remove the glass plate, and with a protractor or a pair of dividers construct a perpendicular BE to AC at the point B. Draw PB and $P'B$ and measure the angle of incidence PBE and the angle of reflection $P'BE$ with the protractor. If a protractor is not at hand, draw an arc with B as a center, cutting the lines PB and $P'B$ at M and O, and measure the lines MN and ON.

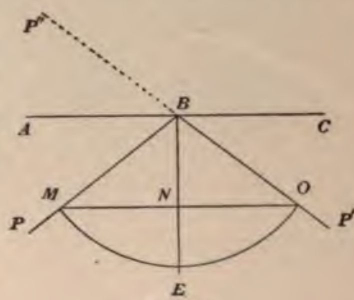


FIG. 87

(*b*) Repeat for some other position of P.

(*c*) Finally, set P at such a point that it is directly in line with its own image P'' and B. Draw the line PB and also construct the perpendicular to AC at B. If the angle of incidence is equal to the angle of reflection, the two lines should exactly coincide.

II. To locate the image formed by a plane mirror. (*a*) Again set up the pin at P (Fig. 88), draw the line AC, and place the edge of the mirror upon it; then lay a straightedge on the paper in successive positions ab, cd, ef, etc., such that the image P'' always appears to lie in the prolongation of the edge of the ruler. Draw the corresponding lines ab, cd, etc.; then remove the glass and locate the image P'' by prolonging these lines to their point of intersection.

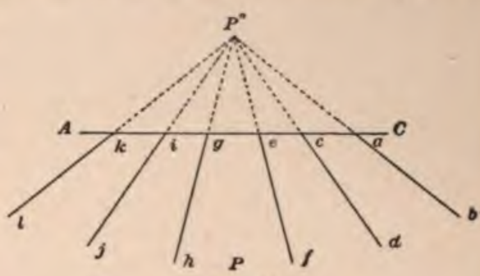


FIG. 88

(*b*) Measure the perpendicular distance from P to AC and from P'' to AC. Also measure the angle which PP'' makes with AC.

Tabulate your results neatly, and state the conclusions which you draw from I and II.

EXPERIMENT 43

TO FIND THE RATIO OF THE VELOCITIES OF LIGHT IN AIR AND GLASS (INDEX OF REFRACTION OF GLASS)

Draw a straight line AC (Fig. 89) across a large sheet of paper and set one edge of the plate-glass prism mnO in exact coincidence with it. Lay a ruler on the paper in such a position that, as you sight along its edge from some position E in the plane mnO, the apex O of the prism, as seen in the face mn, appears to lie in the prolongation of the edge of the ruler. Draw a fine line ab along this edge. Then move the eye to a position E', about as far to the right as E was to the left of the normal to mn, and draw in the same way a line cd. Mark the position of O carefully by means of a pin prick. Then remove the prism, and with an accurate straightedge and a very sharp pencil or knife-edge prolong ab and cd until they meet in some point O'. The point O is then the center *in the glass* of the light waves by means of which you see the apex O, while the point O' is the center of the same waves *after they have emerged into air.* If, therefore, from O and O' as centers, the two arcs qrt and $qr't$ are constructed, the arc qrt would represent the shape and position of the wave from O when it has reached the points q and t, if the speed in air were the same as the speed in glass, while $qr't$ is the actual position of this wave in view of the fact that light travels faster in air than in glass. sr'/sr is then the ratio of these two speeds. But sr'/sr is also the ratio of the *curvatures* of the arcs $qr't$ and qrt; that is, it is the ratio of the amounts by which these curved lines depart from the straight line qst.

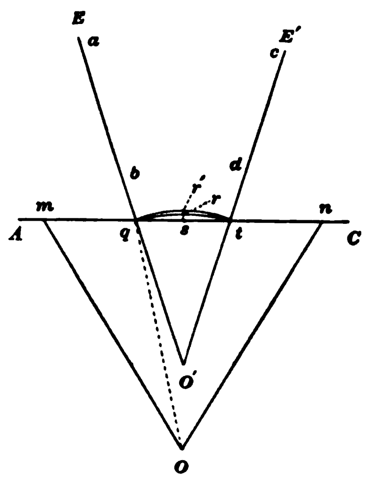


FIG. 89

Now if, at a given point, one arc is curving twice as rapidly as another, it is evident that its center can be but half as far away; that is, the curvatures of two arcs are always inversely proportional to their radii. Hence the ratio sr'/sr is the same as the ratio $Oq/O'q$. Measure these distances as carefully as possible with a meter stick, and record your value for the ratio of the velocities of light in air and glass. This is called the *index of refraction of glass.* Repeat the observations, using different positions of E and E', and see how well the two observations agree.

RECORD OF EXPERIMENT

First Trial	Second Trial	
Oq = ...	Oq = ...	Per cent of difference between first and second = ...
$O'q$ = ...	$O'q$ = ...	
Index = ...	Index = ...	Mean value of index = ...

EXPERIMENT 44

THE CRITICAL ANGLE OF GLASS

Place the plate-glass prism *ABC* (Fig. 90), having three polished faces, upon a large sheet of paper in front of a window *OR* through which the sky is visible. If desired, *OR* may be a piece of ground glass behind which a white light is placed. Place the eye in a position *E*, so as to observe the image of the sky or ground glass as it is seen by reflection from *AB*. A bluish-green line will be seen dividing *AB* into two parts of markedly different brightness.

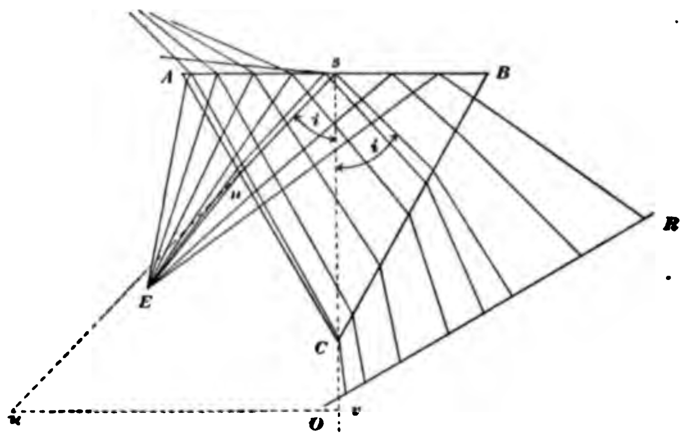


Fig. 90

The part to the right is brighter than the part to the left. If this line dividing the field is not seen at first, it will appear on moving the eye to the left or the right. Move the eye about until the green edge of this line is brought into exact coincidence with a small ink spot placed at *s* on the face *AB*. From the figure it will appear that the light which comes to the eye by reflection from the various points along *AB* must make a larger and larger angle of incidence on *AB* as the point considered lies farther and farther to the right of *A*. When this angle is equal to or greater than the critical angle, as is the case between *s* and *B*, the whole of the light incident upon *AB* is reflected; when it is less than the critical angle, as is the case between *A* and *s*, part is reflected and part transmitted. The bluish-green line which separates the field into parts of unequal brightness represents the position on *AB* at which total reflection begins; that is, the angle *i* is the critical angle for glass. To measure this angle, lay a ruler so that its edge appears to lie in the same straight line with the point *s* and the green edge of the line in the field, and mark with a line on the paper the position *En* of the straightedge. Then with a sharp pencil or a knife draw an outline *ABC* of the prism upon the paper, and place a pin prick at *s* just beneath the ink spot *s* on the face *AB*. Remove the prism and extend *En*, the line just drawn, until it meets *AC* at some point *n*. Connect this point *n* with the pin prick at *s*, erect the perpendicular upon *AB* at *s*, and measure with the protractor the angle *i*. This is the critical angle for glass.

Extend the lines *sn* and the perpendicular at *s* so as to make them from 6 in. to 1 ft. in length. Draw *uv* parallel to *AB*. Then *us*/*uv* should give the same value for the index of refraction as that obtained in the last experiment. The proof of this statement is not suitable for an elementary text, but the measurement will furnish an interesting check as to the accuracy of the results of the experiment.

EXPERIMENT 45

FOCAL LENGTH OF A CONCAVE MIRROR

I. Support the concave mirror in direct sunlight by means of a clamp and let the image of the sun be thrown upon a narrow strip of paper held in front of the mirror. Measure the distance from the mirror to the point at which the spot of light on the thin strip is smallest and brightest. This distance is the focal length; designate it by the letter f.

II. Throw the image of a distant house on the thin strip of paper in the same way. Repeat the above measurement.

III. Place a candle flame or an electric light at a distance D_o, about three times the focal length from the mirror, and locate the position of the image by letting it fall on the narrow screen. Compute the focal length from the formula

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f},$$

in which D_o and D_i are the distances of the object and image respectively from the center of the mirror.

IV. Set up a pin on a block so that its head is nearly opposite the middle of the mirror. Move the pin out to about twice the focal length of the mirror. If the eye is placed in front of the mirror and as much as 8 or 10 in. farther from it than the pin, the object and image may both be seen — the image inverted and the object erect, in the manner shown in another connection in Fig. 92. Shift the position of the pin or of the mirror until the image of the head of the pin is exactly in line with the head of the pin itself. Move the eye to the right and left and see whether there is any relative motion of the pin and its image. If so, it is because they are not the same distance from the eye. The one which is farther away will move to the left when the eye is moved to the left, and to the right when the eye is moved to the right. (Test the correctness of the above statement by holding two pencils in line, but at different distances from the eye, and noticing how they appear to move with reference to each other as the eye is moved from side to side.) Adjust the position of the pin until there is no relative motion between the pin and its image as the eye is moved from side to side. The image of the pin is now at the same place as the pin itself; hence the pin must be at the center of curvature of the mirror. Measure the distance from pin to mirror. This distance is *the radius of curvature of the mirror.* Find what relation exists between this distance and the focal length of the mirror.

RECORD OF EXPERIMENT

Focal length, by I = ...	**Focal length, by III =** ....
Focal length, by II = ...	**One half of radius of mirror =** ....

EXPERIMENT 46

LAWS OF IMAGE FORMATION IN CONVEX LENSES

I. Set up in the positions shown in Fig. 91 a wire netting O, a reading glass L of about 15 cm. focus, and a block B provided with a paper scale s. Set a gas flame behind O to insure bright illumination. Adjust B and L until the image of the netting is sharply outlined on s. Then measure D_o, the distance from O to the middle of the lens L, and D_i, the distance from L to s. Next read on s the number of millimeters covered by ten or twenty squares in the image of the netting. Then with another scale measure the number of millimeters covered by the same number of squares on the netting O. These two observations give respectively the length L_i of the image and the length L_o of the object. Repeat the same observations with three or four different values of D_o, such as 30 cm., 40 cm., 50 cm., and 60 cm., and calculate the focal length f of the lens from the formula

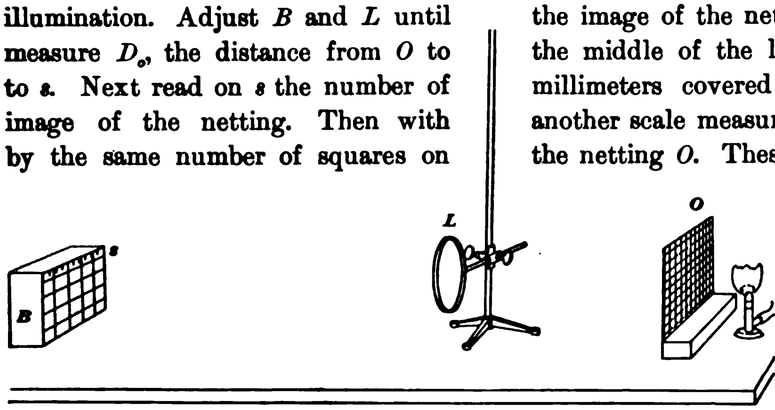


FIG. 91

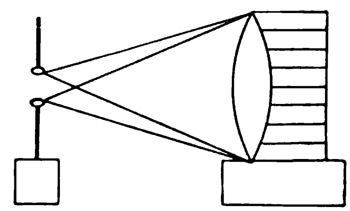


FIG. 92

$$\frac{1}{D_o}+\frac{1}{D_i}=\frac{1}{f}.$$

Also take the ratios L_o/L_i and D_o/D_i and tabulate as indicated in the Record of Experiment.

What conclusion do you draw from the last two columns?

II. Find the focal length of the lens directly by removing O and casting the image of a distant chimney or house upon s.

III. As a final check on the focal length, place a plane mirror behind the lens and mount a pin in front of the lens opposite its center. Adjust the pin by the method of parallax (the method used in Exp. 45, IV), until the image of the head of the pin coincides with the head of the pin itself. The distance from the pin to the center of the lens must then be equal to the focal length of the lens, as is shown by the diagram (Fig. 92), since the waves between the lens and the mirror are plane.

RECORD OF EXPERIMENT

D_o	D_i	$\frac{1}{D_o}+\frac{1}{D_i}$	f	L_o	L_i	$\frac{L_o}{L_i}$	$\frac{D_o}{D_i}$

Focal length (mean of column 4) = ... cm., by II = ... cm., by III = ... cm.

EXPERIMENT 47

MAGNIFYING POWER OF A SINGLE CONVEX LENS

Fig. 93 shows a so-called linen tester — a single convex lens at the focus of which is a square hole in a brass frame. Support the linen tester with a tripod and a clamp so that the lens of the linen tester is 25 cm. from the table top. Place a meter stick on the table directly below the linen tester (Fig. 93).

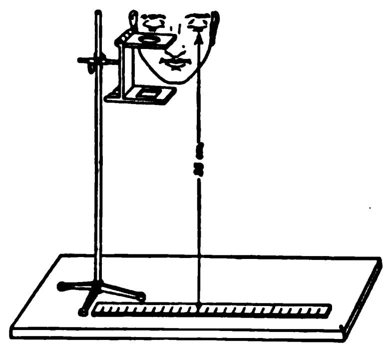


FIG. 93

Place the eye as close as possible to the lens and with both eyes open observe how many millimeters on the stick seen with one eye are covered by the hole seen through the lens with the other eye.

Divide the number thus seen by the measured width of the hole in millimeters. This is obviously the magnifying power, expressed in diameters, of the lens, since it shows how many times as large a diameter of the object appears when seen through the lens as when viewed with the naked eye at the distance of most distinct vision; namely, 25 cm. Measure as accurately as possible the focal length f of the lens (that is, the distance from the middle of the lens to the hole) and see how well the observed magnifying power agrees with the theoretical value; namely, $25/f$.

RECORD OF EXPERIMENT

Number of millimeters covered by the hole on the meter stick	= ....
Width of the hole in millimeters	= ....
∴ magnifying power in diameters (experimental value)	= ....
Focal length of lens in centimeters	= ....
∴ magnifying power in diameters (theoretical value)	= ....

EXPERIMENT 48

THE ASTRONOMICAL TELESCOPE

I. To construct a telescope. With the simple magnifying glass used in the last experiment and with an objective consisting of the reading glass of Exp. 46, construct an astronomical telescope, as follows: Set the reading glass in some support (Fig. 94) and find, with the aid of a piece of white cardboard, the distance F from the lens at which the image of a distant building or window is formed. Then set up the linen tester behind the card at its focal length f from it. Now remove the card and view the image of the distant object through the eyepiece. Slide the eyepiece support, if necessary, until the distant object, preferably a brick wall, is very sharply seen; then measure the distance between the lenses and compare this distance with the sum of the focal lengths. Do you find any simple relation between these quantities? Can you see any reason why there should be some such relation? Explain.

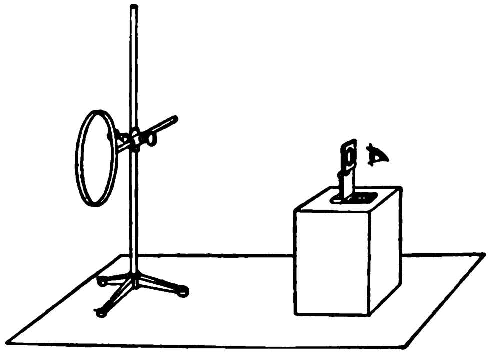


FIG. 94

II. To measure the magnifying power of the telescope. Focus the telescope upon two heavy horizontal marks drawn, for example, on a blackboard on the opposite side of the room. Let the lines be from 3 to 6 in. apart. When the lenses have been adjusted so that a distinct image of the marks is seen with the eye which is looking through the telescope, open the other eye and direct another student to make on the board marks which shall coincide with the apparent positions on the board of the images of the two marks as seen through the telescope. It may be found difficult at first to give attention to both eyes at once, but a little practice will make it easy. Repeat several times and compute the magnifying power M from each observation. Compare this magnifying power with the theoretical value for the magnifying power of a telescope; that is, the ratio of the focal lengths of the objective and the eyepiece. Determine these focal lengths by casting the image of a distant object on a small screen or a sheet of paper.

RECORD OF EXPERIMENT

I. Distance between lenses = ... **cm.**; $F + f$ = ... **cm.**

II. M **(observed)** = ... **diameters.**

M **(theoretical), that is,** $\frac{F}{f}$, = ... **diameters.**

EXPERIMENT 49

THE COMPOUND MICROSCOPE

I. To construct a microscope. Place two corks which contain holes about 1 cm. in diameter in the ends of a cardboard or tin tube 4 or 5 in. long, and with the aid of a rubber band fix the lenses of two of the linen testers over the holes (Fig. 95). Support the tube vertically over the table by means of clamps, and raise or lower it until a magnified image of a millimeter scale lying on a block beneath it is in sharp focus, the distance from the table to the top of the tube being somewhat more than 25 cm.

II. To determine its magnifying power. (*a*) Lay a meter stick on the table, as in Fig. 95, and elevate one end of it until the distance to the stick from the eye which is not looking through the microscope is exactly 25 cm. By fixing the attention simultaneously on the two scales seen, one through the microscope and the other with the unaided eye, determine how many millimeters on the meter stick * are covered by 1 mm. of the scale seen in the microscope; that is, find the number of diameters of magnification of the microscope.

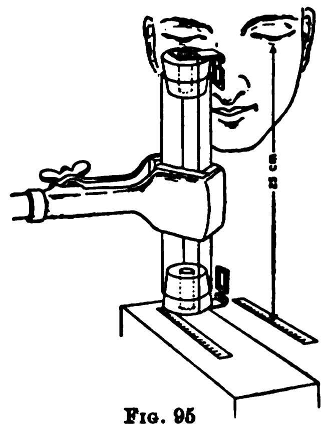


Fig. 95

(*b*) If l_1 is the distance from the objective to the focal plane of the eyepiece, that is, the distance between the centers of the lenses minus the focal length f of the eyepiece, and if l_2 represents the distance from the objective to the object viewed, then l_1/l_2 represents how many times the image formed by the objective is larger than the object. Since the eyepiece magnifies this image $25/f$ times, the total magnifying power M of the compound microscope should be $25/f \times l_1/l_2$. Measure l_1 and l_2 and compare the observed value of M with this calculated value.

RECORD OF EXPERIMENT

(*a*) Observed magnifying power by comparing scales = ... diameters.

(*b*) l_1 = ... cm.; l_2 = ... cm.;

f = ... cm.; $\therefore M = \dfrac{25\, l_1}{f l_2}$ = ... diameters.

* The distance on the meter stick which is covered by 1 mm. of the scale when viewed through the microscope may also be found by marking the projection of the two millimeter marks, as seen through the microscope, on a sheet of paper set 25 cm. from the eye, and then measuring the distance in millimeters between these two marks on the paper. The magnifying power M expressed in diameters is then obviously equal to the above-measured distance expressed in millimeters.

EXPERIMENT 50

PRISMS

I. Path of a beam of light through a prism. Draw a line AC (Fig. 96) on a page of your notebook. Place the prism on the paper in the position indicated in the figure. Light coming to the prism in the direction AC will be bent both upon entering and upon leaving the prism. Place a ruler on the paper and adjust it carefully until it is exactly in line with the apparent direction of AC as seen through the prism. With a sharp pencil draw a line DE along the edge of the ruler, and trace the outline of the prism on the paper. Remove the prism and extend the lines AC and DE until they meet at f and g, the lines which represent the prism faces. Then $AfgE$ will be the path of the light which traverses the prism.

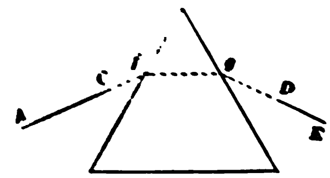


FIG. 96

II. Dispersion. (*a*) With the aid of the knowledge gained in I, place the prism in direct sunlight in such a way that the beam from the sun is thrown upon some shaded portion of the floor. Place between the prism and the sun a sheet of cardboard containing a horizontal slit 2 or 3 mm. wide. Name the colors which you see upon the floor and into which the sunlight has been resolved. Which has suffered the largest bending in passing through the prism, and which the smallest? Cut two 2-mm. slits in the cardboard and leave a 2-mm. space between them. Cover one slit and note the spectrum; then uncover the slit and note the change in color in the middle of the patch where the two spectra overlap. Does this show that the spectral colors may be recombined into white light? Hold the prism alone, without any slit, in the sunlight. Explain now why only the edges of the patch appear colored, while the middle appears uncolored.

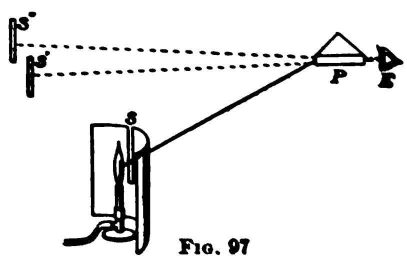


FIG. 97

(*b*) Now place the prism immediately before the eye in such a way that you can observe through it a narrow (2-mm.) strip of white paper placed on a black background, or, better still, an electric-lamp filament or the narrow edge of a gas flame. Explain why the red now appears to be on the side next the base of the prism, while the blue is nearer the apex. Substitute a broad sheet of paper for the narrow strip. When viewed through the prism, one edge will appear red, shading into yellow on the inner side, and the other will appear blue, shading into green. Explain why the paper does not appear colored in the middle, while it does appear colored at the edges. Explain further why the two edges are differently colored.

III. Bright-line spectra. Let one student hold successively in a Bunsen flame, arranged as in Fig. 97, three platinum wires or bits of asbestos, which have been dipped, one in a solution of common salt (sodium chloride), another in lithium chloride, and another in calcium chloride, taking care that the wire itself is kept below the lower edge of the slit *s*. Let other students look through the prisms at distances of about 10 ft., in the manner indicated in the figure, and record the character of the spectra to which the incandescent vapors of these substances give rise.

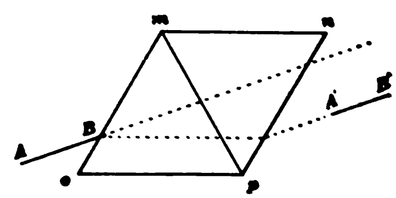


FIG. 98

IV. Path of a beam of light through a plate of glass with parallel faces. (*a*) Place two prisms together in the manner shown in Fig. 98, thus forming in effect a single piece of glass with the parallel edges *om* and *pn*. Draw a heavy line AB, then place a straightedge in line with the image of this line, and draw a mark $A'B'$ along its edge, showing the direction of the light after passing through the

parallel faces *om* and *pn*. From the result obtained, state what happens to the direction of a ray of light which passes through a plate of glass with parallel faces.

(*b*) Slide the two prisms along *om* until the line *AB* meets the first prism nearer its apex. Then slide the other prism along the common face until the perpendicular distance between the faces *mo* and *pn* is just one half as much as before, as shown in Fig. 99. With the same line *AB* and the face *om* exactly parallel to its initial position, draw again a line *A′B′* in the apparent prolongation of *AB*.

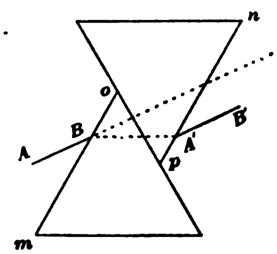


FIG. 99

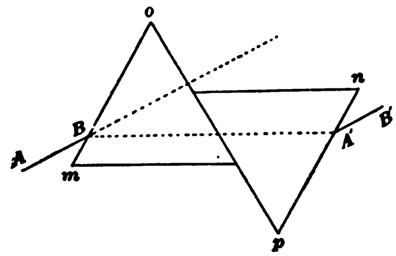


FIG. 100

(*c*) Slide the prisms into the position shown in Fig. 100, being very careful to keep the face *om* parallel to its initial direction. The thickness of glass to be traversed will now be three times as great as in (*b*). Proceed precisely as in (*a*) and (*b*) above.

(*d*) Remove the prisms and prolong *AB*. Measure the perpendicular distances between *AB* and the three prolongations of *AB* as seen through the three thicknesses of glass. State in what way the experiment shows that the lateral displacement of the beam varies with the thickness of the glass.

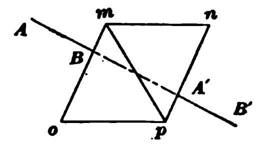


FIG. 101

(*e*) If the prisms are so placed that *AB* is perpendicular to the face *om* (Fig. 101), no trace of the line can be seen at *A′B′*. But if a drop of water is placed between the faces in contact along *mp*, the line *AB* can be seen very plainly at *A′B′*. Explain, remembering that the critical angle for rays of light passing from glass to air is about 42°; while it is about 62° for rays passing from glass to water.

If, now, *A′B′* is drawn as above and if *AB* is exactly perpendicular to *om*, then on removing the prisms and extending *AB* it will be found that *AB* and *A′B′* lie on the same straight line; that is, there has been no lateral displacement. Why?

EXPERIMENT 51

TO MEASURE THE CANDLE POWER OF A WELSBACH BURNER AND OF AN ORDINARY OPEN GAS FLAME AND TO COMPARE THEIR COST OF OPERATION WITH THAT OF A TUNGSTEN LAMP

I. The Welsbach burner. Place a 40 watt (34 C.P.), or a 60 watt (53 C.P.), tungsten lamp* at *A*, and a Welsbach burner at *B* (see Fig. 102). The Welsbach burner should be connected to the gas meter used in Exp. 18.

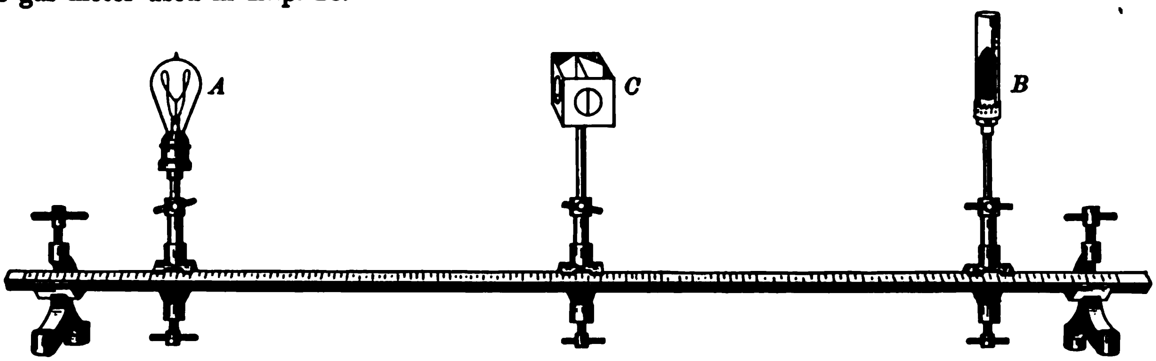


FIG. 102

Slide the photometer *C* along the optical bench until the spot or cross in the photometer appears as nearly as possible the same on both sides. When in this position the spot is evidently illuminated equally by each light. Measure and record the distances $\overline{AC}$ and $\overline{BC}$. If the optical bench has a graduated bar, these distances may be read directly on the bar.

With a watch observe the length of time required for $\frac{1}{2}$ cu. ft. of gas to pass through the burner, using the tungsten lamp for the source of known candle power.

Compute the candle power of the Welsbach burner by use of the equation

$$\frac{\text{C.P. of source of light at } A}{\text{C.P. of source of light at } B} = \frac{\overline{AC}^2}{\overline{BC}^2}.$$

II. The ordinary open gas flame. Replace the Welsbach burner by an ordinary open gas flame and make a set of observations and calculations similar to those made in I.

Questions. *a.* From your data calculate the number of cubic feet of gas consumed per hour by the Welsbach burner and also by the open gas flame.

b. At the price charged by your local gas company for gas compute the cost of operating for 500 hr. a Welsbach burner like that used above. What is the cost per candle power for the same length of time?

c. What is the cost per candle power of operating the open gas flame for 500 hr.?

d. At the price charged by your local power plant for electricity what is the cost per candle power of operating for 500 hr. the tungsten lamp used above?

e. Which of the three sources of light referred to in Questions *b*, *c*, and *d* has the lowest cost of operation per candle power?

f. After taking into account the cost of the mantles required to operate a Welsbach lamp for 500 hr. and also the cost of the tungsten lamps which will give about the same candle power, which method of lighting is the cheaper? This method is approximately how many per cent cheaper than the other method?

* Accurately standardized electric lamps are unnecessary for this experiment, since the relative candle powers of the two sources at *A* and *B* does not depend upon knowing the exact candle power of the tungsten lamp. Therefore the *relative* cost per candle power of operating different lamps is obtained accurately by using the ordinary commercial lamp as a standard and using for its candle power the value given by the maker.

RECORD OF EXPERIMENT

I. The Welsbach burner

Candle power of tungsten lamp = ..., $\overline{AC}$ = ..., $\overline{BC}$ = ...

∴ candle power of Welsbach lamp = ...

Time required to consume $\frac{1}{2}$ cu. ft. of gas = ...

II. The open gas flame

Candle power of tungsten lamp = ..., $\overline{AC}$ = ..., $\overline{BC}$ = ...

∴ candle power of open gas flame = ...

Time required to consume $\frac{1}{2}$ cu. ft. of gas = ...

EXPERIMENT 51 A

THE RELATION BETWEEN INTENSITY OF LIGHT AND DISTANCE

I. Law of inverse squares. (*a*) Light the candle at *A*, and one of the group of four candles at *B*, in Fig. 103. Keep them trimmed so that they burn as nearly as possible alike with flames 3 cm. long.

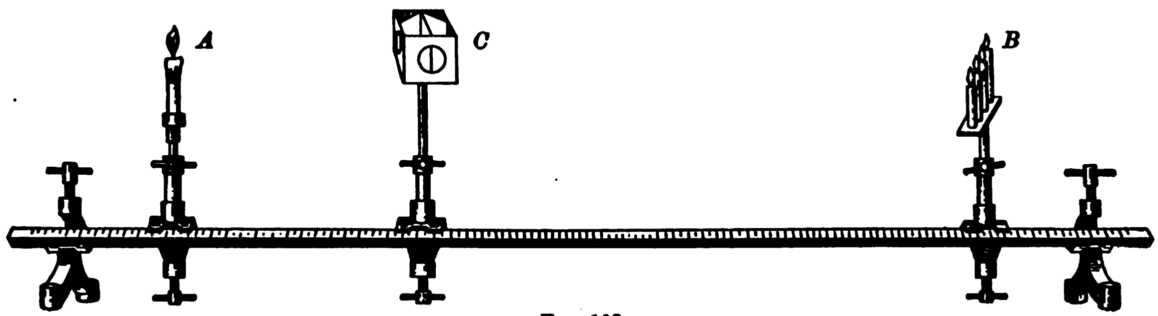


FIG. 103

Slide the photometer *C* along the optical bench until the spot or cross in the photometer appears as nearly as possible the same on both sides. When in this position the spot is evidently equally illuminated on both sides. Measure and record the distances $\overline{AC}$ and $\overline{BC}$. If the optical bench has a graduated bar, these distances may be read directly on the bar.

(*b*) Light two of the group of four candles at *B*. See that all three candles are burning properly. Again slide the photometer *C* to the position in which it is equally illuminated on both sides. Measure and record the distances $\overline{AC}$ and $\overline{BC}$.

(*c*) With three candles at *B* lighted, make a similar set of observations.

(*d*) Make a fourth set of observations when all four candles at *B* are lighted.

In each of the four cases above, compare the ratio of the candle powers of the two sources at *A* and *B* with the ratio of the squares of their respective distances from *C*, as indicated in the data record.

State the law which these ratios indicate must be true.

II. Replace the four candles by a gas flame or by an electric lamp, and find, with the aid of the law proved in I, to how many candles it is equivalent; that is, find its candle power.

Question. How does the intensity of illumination on a screen depend upon the distance when a single source of light is placed at different distances from the screen?

RECORD OF EXPERIMENT

	CANDLES AT *A*	CANDLES AT *B*	$\overline{AC}$	$\overline{BC}$	$\frac{\text{C.P. AT } A}{\text{C.P. AT } B}$	$\frac{\overline{AC}^2}{\overline{BC}^2}$
I. (*a*)	1	1				
(*b*)	1	2				
(*c*)	1	3				
(*d*)	1	4				

II. C.P. of source at $A = 1$. $\overline{AC}$ = ..., $\overline{BC}$ = ... ∴ C.P. of .... at B = ...

APPENDIX A

SUGGESTED TIME SCHEDULE FOR A ONE-YEAR COURSE

CHAPTER	SUBJECT	TIME ALLOTTED	EXPERIMENTS* ACCOMPANYING
I	Measurement	1 week	1–2
II	Pressure in Liquids	1½ weeks	3–5 A
III	Pressure in Air	1½ weeks	6–8
IV	Molecular Motions	2 weeks	9–10 A
V	Force and Motion	2½ weeks	11–13
VI	Molecular Forces	1 week	14–15
VII	Thermometry; Expansion Coefficients	1 week	16–17 A
VIII	Work and Mechanical Energy	2 weeks	18–20
IX	Work and Heat Energy	3 weeks	21–23
X	The Transference of Heat	½ week	24
	Review and finish Laboratory Work	1 week	
	Examinations	1 week	
XI	Magnetism	½ week	25
XII	Static Electricity	1½ weeks	26–27
XIII	Electricity in Motion	2 weeks	28–31 A
XIV	Chemical, Magnetic, and Heating Effects of the Electric Current	1½ weeks	32–34 A
XV	Induced Currents	2 weeks	35–37 A
XVI	Nature and Transmission of Sound	1½ weeks	38–40
XVII	Properties of Musical Sounds	1½ weeks	41–42
XVIII	Nature and Propagation of Light	2 weeks	43–45
XIX	Image Formation	2 weeks	46–48
XX	Color Phenomena	1 week	49–50
XXI	Invisible Radiations	½ week	51 or 51 A
	Review and finish Laboratory Work	1 week	
	Examinations	1 week	
	Total	36 weeks	

* See Preface for the explanation of the numbering of the experiments and the choices of experiments which the system of numbering suggests.

APPENDIX B

RESISTANCES AND WEIGHTS* OF GERMAN-SILVER AND OF COPPER WIRE

BROWN AND SHARP GAUGE

		COPPER WIRE		GERMAN-SILVER WIRE (18 % NICKEL)
Number	Diameter in mils (1 mil = $\frac{1}{1000}$ in.)	Ohms per 1000 ft.	Pounds per 1000 ft.	Ohms per 1000 ft.
6	162.	.4004	79.	7.20
7	144.	.5067	63.	9.12
8	128.	.6413	50.	11.54
9	114.	.8085	39.	14.55
10	102.	1.010	32.	18.18
11	91.6	1.269	25.	22.84
12	80.6	1.601	20.	28.81
13	71.8	2.027	15.7	36.48
14	64.0	2.565	12.4	46.17
15	57.1	3.234	9.8	58.21
16	50.8	4.040	7.9	72.72
17	45.3	5.189	6.1	93.40
18	40.3	6.567	4.8	118.2
19	35.9	8.108	3.9	145.9
20	32.0	10.26	3.1	184.7
21	28.5	12.94	2.5	232.9
22	25.3	16.41	1.9	295.4
23	22.6	20.57	1.5	370.3
24	20.1	26.01	1.2	468.2
25	17.9	32.79	.97	590.2
26	15.9	41.56	.77	748.1
27	14.2	52.11	.61	938.0
28	12.6	66.18	.48	1191.
29	11.3	82.29	.39	1481.
30	10.0	105.1	.30	1892.
31	8.93	132.7	.24	2389.
32	7.95	164.2	.19	2956.
33	7.08	208.4	.15	3751.
34	6.30	264.7	.12	4765.
35	5.61	335.1	.095	5932.
36	5.00	420.3	.076	7565.
37	4.45	530.6	.060	9556.
38	3.97	666.7	.048	12049.
39	3.53	843.3	.038	15431.
40	3.14	1065.	.030	19172.

* The weight per thousand feet of German-silver wire is about 97 per cent of the weight of copper wire of the same diameter.